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Engraved by [illegible]

I had 113 Subscribers at Bath, — at Bristol. I have just finished a Course to 62, and it is likely that I shall begin a second Course on Thursday next to about 24 Subscribers. —

James Ferguson

Published by [illegible]

Cooper Reade

LECTURES

ON

SELECT SUBJECTS

IN

MECHANICS, HYDROSTATICS, PNEUMATICS, OPTICS, AND ASTRONOMY,

BY JAMES FERGUSON, F.R.S.

A NEW AND IMPROVED EDITION,

ADAPTED TO THE PRESENT STATE OF SCIENCE,

BY

C. F. PARTINGTON,

Of the London Institution, Author of an Historical and Descriptive Account of the Steam Engine, &c. &c.

Philosophia mater omnium bonarum artium est. CICERO, i. Tusc.

LONDON:

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1839.

J. Haddon, Castle Street, Finsbury.

TO

JOHN L. ANDERDON, Esq.

DEAR SIR,

As a Patron and Friend to those branches of practical science by which our "Merchants *have become as* princes, and *our* Traffickers the honourable of the earth," allow me to offer, at the shrine of grateful regard, the following pages; which I do the more readily from the opportunity which it affords me of publicly stating how very sincerely

I am, DEAR SIR,

Your faithful

and obliged humble Servant,

CHARLES F PARTINGTON.

LONDON INSTITUTION,
January 1, 1825.

PREFACE.

Ever since the days of the Lord Chancellor Bacon, natural philosophy hath been more and more cultivated in England. That great genius first set out with taking a general survey of all the natural sciences, dividing them into distinct branches, which he enumerated with great exactness. He inquired scrupulously into the degree of knowledge already attained to in each, and drew up a list of what still remained to be discovered; this was the scope of his first undertaking. Afterward he carried his views much farther and shewed the necessity of an experimental philosophy, a thing never before thought of. As he was a professed enemy to systems, he considered philosophy, no otherwise than as that part of knowledge which contributes to make men better and happier: he seems to limit it to the knowledge of things useful, recommending above all the study of nature, and shewing that no progress can be made therein, but by collecting facts and comparing experiments, of which he points out a great number proper to be made.

But notwithstanding the true path to science was thus exactly marked out, the old notions of the schools so strongly possessed people's minds at that time, as not to be eradicated by any new opinions, how rationally soever advanced, until the illustrious Mr. BOYLE, the first who pursued LORD BACON'S plan, began to put experiments in practice with an assiduity equal to his great talents. Next, the ROYAL SOCIETY being established, the true philosophy began to be the reigning taste of the age, and continues so to this day.

The immortal SIR ISAAC NEWTON insisted, even in his early years, that it was high time to banish vague conjectures and hypotheses from natural philosophy, and to bring that science under an entire subjection to experiments and geometry. He frequently called it *the experimental philosophy*, so as to express significantly the difference between it and the numberless systems which had arisen merely out of the conceits of inventive brains: the one subsisting no longer than the spirit of novelty lasts; the other never failing whilst the nature of things remains unchanged.

The method of teaching and laying the foundation of physics, by public courses of experiments, was first undertaken in this kingdom, I believe, by Dr. JOHN KEILL, and since improved and en-

larged by Mr. HAUKSBEE, Dr. DESAGULIERS, Mr WHISTON, Mr. COTES, Mr. WHITESIDE, Dr. BRADLEY, our late Regius and Savilian professor of Astronomy, and the Reverend Dr. BLISS his successor.——Nor has the same been neglected by Dr. JAMES, and Dr. DAVID GREGORY, Sir ROBERT STEWART, and after him Mr. MACLAURIN.——Dr HELSHAM in Ireland, Messrs S'GRAVESANDE and MUSCHENBROEK, and the Abbe NOLLET in France, have also acquired just applause thereby.

The substance of my own attempt in this way of instrumental instruction, the following sheets (exclusive of the astronomical part) will shew: the satisfaction they have generally given, read as lectures to different audiences, affords me some hope that they may be favourably received in the same form by the public.

I ought to observe, that though the five last Lectures cannot be properly said to concern experimental philosophy, I considered, however, that they were not of so different a class, but that they might, without much impropriety, be subjoined to the preceding ones.

My apparatus (part of which is described here, and the rest in a former work*) is rather simple

* Astronomy explained upon SIR ISAAC NEWTON'S principles, and made easy to those who have not studied mathematics.

than magnificent; which is owing to a particular point I had in view at first setting out, namely, to avoid all superfluity, and to render every thing as plain and intelligible as I thought the subject would admit of

TO HIS

ROYAL HIGHNESS

PRINCE EDWARD.

SIR,

As Heaven has inspired your ROYAL HIGHNESS with such a love of ingenious and useful arts, that you not only study their theory, but have often condescended to honour the professors of mechanical and experimental philosophy with your presence and particular favour; I am thereby encouraged to lay myself and the following work at your ROYAL HIGHNESS's feet; and at the same time beg leave to express that veneration with which I am,

SIR,

Your ROYAL HIGHNESS's

Most obliged,

And most obedient,

Humble Servant,

JAMES FERGUSON.

CONTENTS

A

SHORT ACCOUNT

OF THE

LIFE OF THE AUTHOR.

Written by Himself, and continued by the Editor.

AS this is probably the last book I shall ever publish, I beg leave to prefix to it a short account of myself, and of the manner I first began, and have since prosecuted my studies. For, as my setting out in life from a very low station, and in a remote part of the Island, has occasioned some false, and indeed very improbable particulars, to be related of me, I therefore think it the better way instead of contradicting them one by one, to give a faithful and circumstantial detail of my whole proceedings, from my first obscure beginning to the present time; wherein, if I should insert some particulars of little moment, I hope the good-natured reader will kindly excuse me.

I was born in the year 1710, a few miles from Keith, a little village in Bamffshire, in the North of Scotland; and can with pleasure say, that my parents, though poor, were religious and honest;

lived in good repute with all who knew them, and died with good characters.

As my father had nothing to support a large family but his daily labour, and the profits arising from a few acres of land which he rented, it was not to be expected that he could bestow much on the education of his children; yet they were not neglected; for, at his leisure hours, he taught them to read and write. And it was while he was teaching my elder brother to read the Scotch Catechism that I acquired my reading. Ashamed to ask my father to instruct me, I used, when he and my brother were abroad, to take the Catechism, and study the lesson which he had been teaching my brother: and when any difficulty occurred, I went to a neighbouring old woman, who gave me such help as enabled me to read tolerably well before my father had thought of teaching me.

Some time after, he was agreeably surprised to find me reading by myself; he thereupon gave me further instruction, and also taught me to write; which, with about three months I afterwards had at the grammar-school at Keith, was all the education I ever received.

My taste for mechanics arose from an odd accident.—When about 7 or 8 years of age, a part of the roof of the house being decayed, my father, desirous of mending it, applied a prop and lever to an upright spar to raise it to its former situation; and, to my great astonishment, I saw him without considering the reason, lift up the ponder-

ous roof as if it had been a small weight. I attributed this at first to a degree of strength that excited my terror as well as wonder; but thinking farther of the matter, I recollected that he had applied his strength to that end of the lever which was furthest from the prop; and finding on enquiry, that this was the means whereby the seeming wonder was effected, I began making levers (which I then called bars;) and by applying weights to them different ways, I found the power gained by my bar was just in proportion to the lenghts of the different parts of the bar on either side of the prop.—I then thought it was a great pity that, by means of this bar, a weight could be raised but a very little way. On this, I soon imagined, that, by pulling round a wheel, the weight might be raised to any height by tying a rope to the weight, and winding the rope round the axle of the wheel; and that the power gained must be just as great as the wheel was broader than the axle was thick; and found it to be exactly so, by hanging one weight to a rope put round the wheel, and another to the rope that coiled round the axle. So that in, these two machines, it appeared very plain, that their advantage was as great as the space gone through by the working power exceeded the space gone through by the weight; and this property I also thought must take place in a wedge for cleaving wood; but then, I happened not to think of the screw.—By means of a turning lathe which my father had, and sometimes

used, and a little knife, I was enabled to make wheels and other things necessary for my purpose.

I then wrote a short account of these machines, and sketched out figures of them with a pen, imagining it to be the first treatise of the kind that ever was written; but found my mistake, when I afterwards shewed it to a gentleman, who told me that these thiugs were known long before, and shewed me a printed book in which they were treated of: and I was much pleased when I found, that my account (so far as I had carried it) agreed with the principles of mechanics in the book he shewed me. And from that time my mind preserved a constant tendency to improve in that science.

But, as my father could not afford to maintain me while I was in pursuit of these matters only, and I was rather too young and weak for hard labour, he put me out to a neighbour to keep sheep, which I continued to do for some years; and in that time I used to study the stars in the night. In the day-time I amused myself by making models of mills, spinning-wheels, and such other things as I happened to see.

I then went to serve a considerable farmer in the neighbourhood, whose name was James Glashan. I found him very kind and indulgent; but he soon observed, that in the evenings, when my work was over, I went into a field with a blanket about me, lay down on my back, and stretched a thread with small beads upon it, at arms'

length, between my eye and the stars; sliding the beads upon it till they hid such and such stars from my eye, in order to take their apparent distances from one another; and then, laying a thread down on a paper, I marked the stars thereon by the beads, according to their respective positions, having a candle by me. My master at first laughed at me; but, when I explained my meaning to him, he encouraged me to go on: and that I might make fair copies in the day-time of what I had done in the night, he often worked for me himself. I shall always have a respect for the memory of that man.

One day he happened to send me with a message to the Reverend Mr. John Gilchrist, minister at Keith, to whom I had been known from my childhood. I carried my star papers to shew them to him, and found him looking over a large parcel of maps, which I surveyed with great pleasure, as they were the first I had ever seen. He then told me that the earth is round like a ball, and explained the map of it to me. I requested him to lend me *that* map, to take a copy of it in the evenings. He cheerfully consented to this, giving me at the same time a pair of compasses, a ruler, pens, ink, and paper; and dismissing me with an injunction not to neglect my master's business by copying the map, which I might keep as long as I pleased.

For this pleasant employment, my master gave me more time than I could reasonably expect;

and often took the threshing-flail out of my hands, and worked himself, while I sat by him in the barn, busy with my compasses, ruler, and pen.

When I had finished the copy, I asked leave to carry home the map: he told me I was at liberty to do so, and might stay two hours to converse with the minister.—In my way thither, I happened to pass by the school at which I had been before, and saw a genteel-looking man (whose name I afterwards learned was Cantley) painting a sun-dial on the wall. I stopped awhile to observe him, and the school-master came out, and asked me what parcel it was that I had under my arm. I I shewed him the map, and the copy I had made of it, wherewith he appeared to be very well pleased, and asked me whether I should not like to learn of Mr. Cantley to make sun-dials. Mr. Cantley looked at the copy of the map, and commended it much; telling the school-master (Mr. John Skinner) that it was a pity I did not meet with notice and encouragement. I had a good deal of conversation with him, and found him to be quite affable and communicative; which made me think I should be extremely happy if I could be further aquainted with him.

I then proceeded with the map to the minister, and shewed him the copy of it.—While we were conversing together, a neighbouring gentleman, Thomas Grant, Esq. of Achoynaney, happened to come in; and the minister immediately introduced me to him, shewing him what I had done. He ex

pressed great satisfaction, asked me some questions about the construction of maps, and told me that if I would go and live at his house, he would order his butler, Alexander Cantley, to give me a great deal of instruction. Finding that this Cantley was the man whom I had seen painting the sun-dial, and of whom I had already conceived a very high opinion, I told 'Squire Grant, that I should rejoice to be at his house as soon as the time was expired for which I was engaged with my present master.—He very politely offered to put one in my place; but this I declined.

When the term of my servitude was out, I left my good master, and went to the gentleman's house, where I quickly found myself with a most humane good family. Mr. Cantley the butler soon became my friend, and continued so till his death. He was the most extraordinary man that ever I was acquainted with, or perhaps ever shall see; for he was a complete master of arithmetic, a good mathematician, a master of music on every known instrument except the harp, understood Latin, French, and Greek, let blood extremely well, and could even prescribe as a physician upon any urgent occasion. He was what is generally called *self-taught;* but, I think, he might with much greater propriety have been termed GOD ALMIGHTY'S scholar.

He immediately began to teach me decimal arithmetic, and algebra; for I had already learned vulgar arithmetic, at my leisure hours, from books.

He then proceeded to teach me the elements of geometry; but to my inexpressible grief, just as I was beginning that branch of science, he left Mr. Grant, and went to the late earl of Fife's, at several miles distance. The good family I was then with could not prevail with me to stay after he was gone; so I left them, and went to my father's.

He had made me a present of Gordon's Geographical Grammar, which, at that time, was to me a great treasure. There is no figure of a globe in it, although it contains a tolerable description of the globes, and their use. From this description I made a globe in three weeks at my father's, having turned the ball thereof out of a piece of wood; which ball I covered with paper, and delineated a map of the world upon it; made the meridian ring and horizon of wood; covered them with paper, and graduated them; and was happy to find, that, by my globe (which was the first I ever saw) I could solve the problems.

But this was not likely to afford me bread, and I could not think of staying with my father, who I knew full well could not maintain me in that way, as it could be of no service to him; and he had without my assistance, hands sufficient for all his work.

I then went to a miller, thinking it would be a very easy business to attend the mill, and that I should have a great deal of leisure time to study decimal arithmetic and geometry. But my master being too fond of tipling at an ale-

house, left the whole care of the mill to me, and almost starved me for want of victuals; so that I was glad when I could have a little oat-meal mixed with cold water to eat. I was engaged for a year in that man's service, at the end of which I left him, and returned in a very weak state to my father's.

Soon after I had recovered my former strength, a neighbouring farmer, who practised as a physician in that part of the country, came to my father's, wanting to have me as a labouring servant. My father advised me to go to Doctor Young, telling me that the Doctor would instruct me in that part of his business. This he promised to do, which was a temptation to me. But instead of performing his promise, he kept me constantly to very hard labour, and never once shewed me one of his books. All his servants complained that he was the hardest master they had ever lived with; and it was my misfortune to be engaged with him for half a year. But, at the end of three months, I was so much overwrought, that I was almost disabled, which obliged me to leave him: and he was so unjust as to give me nothing at all for the time I had been with him, because I did not complete my half-year's service; though he knew that I was not able, and had seen me working for the last fortnight, as much as possible with one hand and arm, when I could not lift the other from my side. And what I thought was particularly hard, he never once tried to give me

the least relief, further than once bleeding me, which rather did me hurt than good, as I was very weak and much emaciated. I then went to my father's, where I was confined for two months on account of my hurt, and despaired of ever recovering the use of my left arm. And, during all that time, the Doctor never once came to see me, although the distance was not quite two miles.—But my friend Mr. Cantley, hearing of my misfortune, at twelve miles' distance, sent me proper medicines and applications, by means of which I recovered the use of my arm; but found myself too weak to think of going into service again, and had entirely lost my appetite, so that I could take nothing but a draught of milk once a-day, for many weeks.

In order to amuse myself in this low state, I made a wooden clock, the frame of which was also of wood; and it kept time pretty well. The bell, on which the hammer struck the hours, was the neck of a broken bottle.

Having then no idea how any time-keeper could go but by a weight and a line, I wondered how a watch could go in all positions; and was sorry that I had never thought of asking Mr. Cantley, who could very easily have informed me. But happening one day to see a gentleman ride by my father's house, (which was close by a public road) I asked him what o'clock it then was: he looked at his watch, and told me. As he did that with so much good nature, I begged of him to

shew me the inside of his watch: and though he was an entire stranger, he immediately opened the watch, und put it into my hands. I saw the spring-box with part of the chain round it, and asked him what it was that made the box turn round: he told me that it was turned round by a steel spring within it. Having then never seen any other spring than that of my father's gun-lock, I asked how a spring within a box could turn the box so often round as to wind all the chain upon it. He answered, that the spring was long and thin; that one end of it was fastened to the axis of the box, and the other end to the inside of the box; that the axis was fixed, and the box was loose upon it. I told him I did not yet thoroughly understand the matter: Well, my lad, says he, take a long thin piece of whalebone, hold one end of it fast between your finger and thumb, and wind it round your finger: it will then endeavour to unwind itself; and if you fix the other end of it to the inside of a small hoop, and leave it to itself, it will turn the hoop round and round, and wind up a thread tied to the outside of the hoop. —I thanked the gentleman, and told him that I understood the thing very well. I then tried to make a watch with wooden wheels, and made the spring of whalebone; but found that I could not make the watch go when the balance was put on, because the teeth of the wheels were rather too weak to bear the force of a spring sufficient to move the balance; although the wheels would run

fast enough when the balance was taken off. I inclosed the whole in a wooden case, very little bigger than a breakfast tea-cup: but a clumsy neighbour one day looking at my watch, happened to let it fall; and, turning hastily about to pick it up, set his foot upon it, and crushed it all to pieces; which so provoked my father, that he was almost ready to beat the man; and discouraged me so much, that I never attempted to make such another machine again, especially as I was thoroughly convinced that I could never make one that would be of any real use.

As soon as I was able to go abroad, I carried my globe, clock, and copies of some other maps besides that of the world, to the late Sir James Dunbar of Durn (about seven miles from where my father lived) as I had heard that Sir James was a very good-natured, friendly, inquisitive gentleman. He received me in a very kind manner, was pleased with what I shewed him, and desired I would clean his clocks. This, for the first time, I attempted; and then began to pick up some money in that way about the country, making Sir James's house my home, at his desire.

Two large globular stones stood on the top of his gate: on one of them I painted (with oil colours) a map of the terrestrial globe, and on the other a map of the celestial, from a planisphere of the stars which I copied on paper from a celestial globe belonging to a neighbouring gentleman. The poles of the painted globes stood towards

the poles of the heavens; on each, the 24 hours were placed around the equinoctial, so as to shew the time of the day when the sun shone out, by the boundary where the half of the globe at any time enlightened by the sun was parted from the other half in the shade; the enlightened parts of the terrestrial globe answering to the like enlightened parts of the earth at all times. So that, whenever the sun shone on the globe, one might see to what places the sun was then rising, to what places it was setting, and all the places where it was then day or night throughout the earth.

During the time I was at Sir James's hospitable house, his sister, the honourable Lady Dipple, came there on a visit, and Sir James introduced me to her. She asked me whether I could draw patterns for needlework on aprons and gowns. On shewing me some, I undertook the work, and drew several for her; some of which were copied from her patterns, and the rest I did according to my own fancy. On this I was sent for by other ladies in the country, and began to think myself growing very rich by the money I got for such drawings; out of which I had the pleasure of occasionally supplying the wants of my poor father.

Yet all this while I could not leave off star-gazing in the nights, and taking the places of the planets among the stars by my above-mentioned thread. By this, I could observe how the planets changed their places among the stars, and deline-

ated their paths on the celestial map, which I had copied from the above-mentioned celestial globe.

By observing what constellations the ecliptic passed through in that map, and comparing these with the starry heaven, I was so impressed as sometimes to imagine that I saw the ecliptic in the heaven, among the stars, like a broad circular road for the sun's apparent course; and fancied the paths of the planets to resemble the narrow ruts made by cart-wheels, sometimes on one side of a plain road, and sometimes on the other, crossing the road at small angles, but never going far from either side of it.

Sir James's house was full of pictures and prints, several of which I copied with pen and ink: this made him think I might become a painter.

Lady Dipple had been but a few weeks there, when William Baird, Esq. of Auchmedden, came on a visit: he was the husband of one of that lady's daughters, and I found him to be very ingenious and communicative; he invited me to go to his house, and stay some time with him, telling me that I should have free access to his library, which was a very large one; and that he would furnish me with all sorts of implements for drawing. I went thither, and stayed about eight months; but was much disappointed in finding no books on astronomy in his library, except what was in the two volumes of Harris's Lexicon Technicum, although there were many books on geography and other sciences: several of these in-

deed were in Latin, and more in French; which being languages that I did not understand, I had recourse to him for what I wanted to know of these subjects, which he cheerfully read to me; and it was as easy for him, at sight, to read English from a Greek, Latin, or French book, as from an English one. He furnished me with pencils and Indian ink, shewing me how to draw with them; and although he had but an indifferent hand at that work, yet he was a very acute judge; and consequently a very fit person for shewing me how to correct my own work. He was the first who ever sat to me for a picture, and I found it was much easier to draw from the life than from any picture whatever, as nature was more striking than any imitation of it.

Lady Dipple came to his house in about half a year after I went thither. And as they thought I had a genius for painting, they consulted together about what might be the best way to put me forward. Mr. Baird thought it would be no difficult matter to make a collection for me among the neighbouring gentlemen, to put me to a painter at Edinburgh: but he found, upon trial, that nothing worth the while could be done among them. And as to himself, he could not do much that way, because he had but a small estate, and a very numerous family. Lady Dipple told me that she was to go to Edinburgh next spring, and that if I would go thither, she would give me a year's bed and board at her house *gratis*, and make all the

interest she could for me among her acquaintance there.—I thankfully accepted of her kind offer; and instead of giving me one year, she gave me two. I carried with me a letter of recommendation from Lord Pitsligo, a near neighbour of 'Squire Baird's, to Mr. John Alexander, a painter in Edinburgh; who allowed me to pass an hour every day at his house, for a month, to copy from his drawings; and said he would teach me to paint in oil-colours, if I would serve him seven years, and my friends would maintain me all that time; but this was too much for me to desire them to do; nor did I choose to serve so long. I was then recommended to other painters, but they would do nothing without money. So I was quite at a loss what to do.

In a few days after this, I received a letter of recommendation from my good friend 'Squire Baird to the Reverend Dr. Robert Keith at Edinburgh, to whom I gave an account of my bad success among the painters there. He told me, that if I would copy from nature, I might do without their assistance; as all the rules for drawing signified but very little when one came to draw from the life, and, by what he had seen of my drawings brought from the North, he judged I might succeed very well in drawing pictures from the life, in Indian ink, on vellum. He then sat to me for his own picture, and sent me with it and a letter of recommendation to the Right Honourable Lady Jane Douglas, who lived with her mother,

the Marchioness of Douglas, at Merchiston-house, near Edinburgh. Both the Marchioness and Lady Jane behaved to me in the most friendly manner, on Dr. Keith's account, and sat for their pictures; telling me at the same time, that I was in the very room in which Lord Napier invented and computed the Logarithms; and that, if I thought it would inspire me, I should always have the same room whenever I came to Merchiston. —I staid there several days, and drew several pictures of Lady Jane; of whom it was hard to say, whether the greatness of her beauty, or the goodness of her temper and dispositions, was the most predominant. She sent these pictures to ladies of her acquaintance, in order to recommend me to them; by which means I soon had as much business as Icould possibly manage, so as not only to put a good deal of money into my own pocket, but also to spare what was sufficient to help to supply my father and mother in their old age.—Thus a business was providentially put into my hands, which I followed for six and twenty years.

Lady Dipple, being a woman of the strictest piety, kept a watchful eye over me at first, and made me give her an exact account at night of what families I had been in throughout the day, and of the money I had received. She took the money each night, desiring I would keep an account of what I had put into her hands; telling me that I should duly have out of it what I wanted for clothes, and to sent to my father.—But, in less

than half a year, she told me that she would thenceforth trust me with being my own banker; for she had made a good deal of private enquiry how I had behaved when I was out of her sight through the day, and was satisfied with my conduct.

During my two years' stay at Edinburgh, I somehow took a violent inclination to study anatomy, surgery, and physic, all from reading of books, and conversing with gentlemen, on these subjects; which, for that time, put all thoughts of astronomy out of my mind, and I had no inclination to become acquainted with any one there who taught either mathematics or astronomy: for nothing would serve me but to be a Doctor.

At the end of the second year I left Edinburgh, and went to see my father, thinking myself tolerably well qualified to be a physician in that part of the country; and I carried a good deal of medicines, plaisters, &c. thither.—But, to my mortification, I soon found that all my medical theories and study were of little use in practice. And then, finding that very few paid me for the medicines they had, and that I was far from being so successful as I could wish, I quite left off that business, and began to think of taking to the more sure one of drawing pictures again.—For this purpose I went to Inverness, where I had eight months' business.

When I was there, I began to think of astronomy again; and was heartily sorry for having

quite neglected it at Edinburgh, where I might have improved my knowledge by conversing with those who were very able to assist me.—I began to compare the ecliptic with its twelve signs (through which the sun goes in twelve months) to the circle of twelve hours on the dial-plate of a watch, the hour-hand to the sun, and the minute-hand to the moon, moving in the ecliptic; the one always overtaking the other at a place forwarder than it did at their last conjunction before. On this, I contrived and finished a scheme on paper for shewing the motions and places of the sun and moon in the ecliptic on each day of the year, perpetually; and consequently, the days of all the new and full moons.

To this I wanted to add a method for shewing the eclipses of the sun and moon; of which I knew the cause long before, by having observed that the moon was, for one half of her period, on the north side of the ecliptic, and for the other half on the south. But, having not observed her course long enough among the stars by my above-mentioned thread, so as to delineate her path on my celestial map, in order to find the two opposite points of the ecliptic in which her orbit crosses it, I was altogether at a loss how and where in the ecliptic (in my scheme) to place these intersecting points: this was in the year 1739.

At last, I recollected, that when I was with Squire Grant, of Achoynaney, in the year 1730, I had read, that, on the first of January, 1690,

the moon's ascending node was in the 10th minute of the first degree of Aries; and that her nodes moved backward through the whole ecliptic in 18 years and 224 days, which was at the rate of 3 min. 11 sec. every 24 hours. But, as I scarcely knew, in the year 1730, what the moon's nodes meant, I took no further notice of it at that time.

However, in the year 1739, I set to work at Inverness; and after a tedious calculation of the slow motion of the nodes from Jan. 1690 to Jan. 1740, it appeared to me, that (if I was sure I had remembered right) the moon's ascending node must be in 23 deg. 25 min. of Cancer, at the beginning of the year 1740. And so I added the eclipse-part to my scheme, and called it *The Astronomical Rotula.*

When I had finished it, I shewed it to the Rev. Mr. Alexander Mac Bean, one of the ministers at Inverness, who told me he had a set of almanacks by him for several years past, and would examine it by the eclipses mentioned in them. We examined it together, and found that it agreed throughout with the days of all the new and full moons and eclipses mentioned in these almanacks; which made me think I had constructed it upon true astronomical principles. On this, Mr. Mac Bean desired me to write to Mr. Mac Laurin, professor of the mathematics at Edinburgh, and give him an account of the methods by which I had formed my plan, requesting him to correct it where it was wrong. He returned me a most polite and friendly

answer (although I had never seen him during my stay at Edinburgh) and informed me that I had only mistaken the radical mean place of the ascending node by a quarter of a degree; and that, if I would send the drawing of my Rotula to him, he would examine it, and endeavour to procure me a subscription to defray the charges of engraving it on copper-plates, if I chose to publish it. I then made a new and correct drawing of it, and sent it to him, who soon got me a very handsome subscription by setting the example himself, and sending subscription-papers to others.

I then returned to Edinburgh, and had the Rotula-plates engraved there by Mr. Cooper.* It has gone through several impressions, and always sold very well till the year 1752, when the style was changed, which rendered it quite useless.—Mr. Mac Laurin received me with the greatest civility when I first went to see him at Edinburgh. He then became an exceedingly good friend to me, and continued so till his death.

One day I requested him to shew me his orrery, which he immediately did. I was greatly delighted with the motions of the earth and moon in it, and would gladly have seen the wheel-work, which was concealed in a brass box, and the box and planets above it were surrounded by an armillary sphere. But he told me, that he never had opened it; and I could easily perceive that it could

* Cooper was master to the justly celebrated Mr. Robert Strange, who was at that time his apprentice.

not be opened but by the hand of some ingenious clock-maker, and not without a great deal of time and trouble.

After a good deal of thinking and calculation, I found that I could contrive the wheel-work for turning the planets in such a machine, and giving them their progressive motions; but should be very well satisfied if I could make an orrery to shew the motions of the earth and moon, and of the sun round its axis. I then employed a turner to make me a sufficient number of wheels and axles, according to patterns which I gave him in drawing: and after having cut the teeth in the wheels by a knife, and put the whole together, I found that it answered all my expectations. It shewed the sun's motion round his axis, the diurnal and annual motions of the earth on its inclined axis, which kept its parallelism in its whole course round the sun; the motions and phases of the moon, with the retrograde motion of the nodes of her orbit; and consequently, all the variety of seasons, the different lengths of days and nights, the days of the new and full moons, and eclipses.

When it was all completed, except the box that covers the wheels, I shewed it to Mr. Mac Laurin, who commended it in presence of a great many young gentlemen who attended his lectures. He desired me to read them a lecture on it, which I did without any hesitation, seeing I had no reason to be afraid of speaking before a great and good man who was my friend.—Soon after that, I sent

it in a present to the Reverend and ingenious Mr. Alexander Irvine, one of the ministers at Elgin in Scotland.

I then made a smaller and neater orrery, of which all the wheels were of ivory, and I cut the teeth in them with a file. This was done in the beginning of the year 1743; and, in May that year, I brought it with me to London, where it was soon after brought by Sir Dudley Rider. I have made six orreries since that time, and there are not any two of them in which the wheel-work is alike: for I could never bear to copy one thing of that kind from another, because I still saw there was great room for improvements.

I had a letter of recommendation from Mr. Baron Eldin at Edinburgh to the Right Honourable Stephen Poyntz, Esq; at St. James's, who had been preceptor to his Royal Highness the late Duke of Cumberland, and was well known to be possessed of all the good qualities that can adorn a human mind.—To me, his goodness was really beyond my power of expression; and I had not been a month in London till he informed me that he had wrote to an eminent professor of mathematics to take me into his house, and give me board and lodging with all proper instructions to qualify me for teaching a mathematical school he (Mr. Poyntz) had in view for me, and would get me settled in it. This I should have liked very well, especially as I began to be tired of drawing pictures, in which, I confess, I never strove to excel, because my mind

was still pursuing things more agreeable. He soon after told me he had just received an answer from the mathematical master, desiring I might be sent immediately to him. On hearing this, I told Mr. Poyntz, that I did not know how to maintain my wife during the time I must be under the master's tuition. What, says he, are you a married man? I told him I had been so ever since May in the year 1739. He said he was sorry for it, because it quite defeated his scheme; as the master of the school he had in view for me must be a bachelor.

He then asked me, what business I intended to follow? I answered, that I knew of none besides that of drawing pictures. On this he desired me to draw the pictures of his lady and children, that he might shew them in order to recommend me to others; and told me, that, when I was out of business, I should come to him, and he would find me as much as he could and I soon found as much as I could execute: but he died in a few years after, to my inexpressible grief.

Soon afterward, it appeared to me, that although the moon goes round the earth, and that the sun is far on the outside of the moon's orbit, yet the moon's motion must be in a line that is always concave towards the sun: and upon making a delineation representing her absolute path in the heavens, I found it to be really so. I then made a simple machine for delineating both her path and the earth's on a long paper laid on the floor. I

carried the machine and delineation to the late Martin Folkes, Esq. President of the Royal Society, on a Thursday afternoon. He expressed great satisfaction at seeing it, as it was a new discovery; and took me that evening with him to the Royal Society, where I shewed the delineation, and the method of doing it.

When the business of the society was over, one of the members desired me to dine with him next Saturday at Hackney; telling me that his name was Ellicott, and that he was a watch-maker.

I accordingly went to Hackney, and was kindly received by Mr. John Ellicott, who then shewed me the very same kind of delineation, and part of the machine by which he had done it; telling me that he had thought of it twenty years before. I could easily see, by the colour of the paper, and of the ink-lines upon it, that it must have been done many years before I saw it. He then told me what was very certain, that he had neither stolen the thought from me, nor had I from him. And from that time till his death, Mr. Ellicott was one of my best friends. The figure of this machine and delineation is in the 7th Plate of my book of Astronomy.

Soon after the style was changed, I had my Rotula new engraved; but have neglected it too much by not fitting it up and advertizing it. After this, I drew out a scheme, and had it engraved, for shewing all the problems of the Rotula except the eclipses: and in place of that, it shews the times

of rising and setting of the sun, moon, and stars; and the positions of the stars for any time of the night.

In the year 1747, I published a Dissertation on the Phenomena of the Harvest Moon, with the description of a new Orrery, in which there were only four wheels. But having never had a grammatical education, nor time to study the rules of just composition, I acknowledge that I was afraid to put it to press; and, for the same cause, I ought to have the same fears still. But having the pleasure to find that this, my first work, was not ill received, I was emboldened to go on, in publishing my Astronomy, Mechanical Lectures, Tables and Tracts relative to several Arts and Sciences, The Young Gentleman and Lady's Astronomy, a small treatise on Electricity, and the following sheets.

In the year 1748, I ventured to read Lectures on the Eclipse of the Sun that fell on the 14th of July in that year. Afterwards I began to read Astronomical Lectures on an Orrery which I made, and of which the figures of all the wheel-work are contained in the 6th and 7th Plates of this book.* I next began to make an apparatus for Lectures on Mechanics, and gradually increased the apparatus for other parts of experimental philosophy, buying from others what I could not make for myself, till I brought it to its present state.—I then entirely

* Mechanical Exercises, 8vo.

left off drawing pictures, and employed myself in the much pleasanter business of reading Lectures on Mechanics, Hydrostatics, Hydraulics, Pneumatics, Electricity, and Astronomy: in all which, my encouragement has been greater than I could have expected.

The best machine I ever contrived is the *Eclipsareon*, of which there is a figure in the 13th Plate of my Astronomy. It shews the time, quantity, duration, and progress of the solar eclipses, at all parts of the earth. My next best contrivance is the universal dialing cylinder, of which there is a figure in the 8th Plate of the Supplement to my Mechanical Lectures.

It is now thirty years since I came to London; and during all that time, I have met with the highest instances of friendship from all ranks of people both in town and country, which I here acknowledge with the utmost respect and gratitude; and particularly the goodness of our present gracious Sovereign, who, out of his privy purse, allows me fifty pounds a-year, which is regularly paid without any deduction.

At the period when our Author concludes his Memoir, he had acquired a large funded property, and appeared likely to enjoy a considerable share of that repose, which his previous labours so justly merited. A series of misfortunes, how-

[illegible] in the evening of a well-[illegible] and accom-[illegible] disappeared: and [illegible] narrowly [illegible]. These and other circum-[illegible] similar nature, gradually impaired [illegible] ultimately [illegible] accumulated infirmities, [illegible] of November, 1776.

[illegible] his death, Mr. Fergu-[illegible] visiting the royal [illegible] Kew and St. James's, his late Ma-[illegible] company and [illegible] science. He was also [illegible] a member of the Royal Society, without [illegible] the usual admission fee, an honour seldom [illegible] the most distinguished [illegible].*

* [illegible] Mr. Ferguson's success as a public Lecturer, may be [illegible] Letter, which forms part of the valuable [illegible] Editor's friend, William Upcott, Esq. [illegible] remembered that the Letter [illegible] little praised by the scanty popu-[illegible].

[illegible] Sir, Bristol, May [illegible] 1774.

[illegible] Bath [illegible] Bristol I have just finished a course [illegible] I shall begin a second course on Thursday [illegible] health is far from being good.

Considering the [illegible] I cannot [illegible] my six books [illegible] to the public Library here, and am [illegible].

[illegible] Sir,

Your most obliged [illegible] servant,

JAMES FERGUSON.

Amongst the poetical admirers of Mr. Ferguson, we may place the late Mr. Capel Loft, who in his Eudosia, or a Poem on the Universe, has the following elegant allusion to the early labours of our Author:—

> "Nor shall thy guidance not conduct our feet,
> O honour'd Shepherd of our later days!
> Whom from the flocks, while thy untutor'd soul,
> Mature in childhood, trac'd the starry course,
> Astronomy, enamour'd, gently led
> Through all the splendid labyrinths of Heaven;
> And taught thee her stupendous laws; uncloth'd
> In all the light of fair simplicity,
> Thy apt expression."

THE FOLLOWING IS AN ACCURATE LIST OF MR. FERGUSON'S PUBLISHED WORKS.

Description of a new Orrery. Lond. 1745, 4to.

Dissertation on the Phænomena of the Harvest Moon; also, The Description and Use of a new four-wheeled Orrery; and an Essay upon the Moon's turning round her own axis. Lond. 1747. 8vo.

A brief Description of the Solar System; to which is subjoined, an Astronomical Account of the year of our Saviour's Crucifixion. Lond. 1754, 8vo.

An idea of the Material Universe, deduced from a Survey of the Solar System. Lond. 1754. 8vo. 1s.

Astronomy explained, upon Sir Isaac Newton's Principles, and made easy to those who have not studied Mathematics. Lond. 1756, 1757, 4to. 15s.

The same; to which is added, A plain Method of finding the distances of all the Planets from the Sun, by the transit of Venus over the Sun's disk. Lond. 1764, 4to. 5th edit. 1772.

LECTURES

ON

SELECT SUBJECTS.

LECTURE I.

OF MATTER AND ITS PROPERTIES.

LECT. I.

AS the design of the first part of this course is to explain and demonstrate those laws by which the material universe is governed, regulated, and continued; and by which the various appearances in nature are accounted for; it is necessary to begin with explaining the properties of matter.

Matter, what.

By the word *matter* is here meant every thing that has length, breadth, and thickness, and resists the touch.

Its properties.

The inherent properties of matter are solidity, inactivity, mobility, and divisibility.

Solidity

The *solidity* of matter arises from its having length, breadth, thickness; and hence it is that all bodies are comprehended under some shape or other, and that each particular body hinders all others from occupying the same part of space which it possesseth. Thus, if a piece of wood or metal be squeezed ever so hard between two plates, they cannot be brought into contact. And even water or air has this property; for if a small quantity of it be fixed between any other bodies, they cannot be brought to touch one another.[1]

Note 1. By solidity or impenetrability in common language, is understood the property of not being easily separated into parts,—a

LECT. I. Inactivity.

A second property of matter is *inactivity* or *passiveness*; by which it always endeavours to continue in the state that it is in, whether of rest or motion. And therefore, if one body contains twice or thrice as much matter as another body does, it will have twice or thrice as much inactivity; that is, it will require twice or thrice as much force to give it an equal degree of motion, or to stop it after it hath been put into such a motion.

That matter can never put itself into motion is allowed by all men. For they see that a stone, lying on the plane surface of the earth, never removes itself from that place, nor does any one imagine it ever can. But most people are apt to believe that all matter has a propensity to fall from a state of motion into a state of rest; because they see that if a stone or a cannon-ball be put into ever so violent a motion, it soon stops: not considering that this stoppage is caused, 1. By the gravity or weight of the body, which sinks it to the ground in spite of the impulse; and, 2. By the resistance of the air through which it moves, and by which its velocity is retarded every moment till it falls.

A bowl moves but a short distance upon a bowling-green; because the roughness and unevenness of the grassy surface soon creates friction enough to stop it. But if the green were perfectly level, and covered with polished glass, and the bowl were perfectly hard, round, and smooth, it would go a great way farther, as it would have nothing but the air to resist it; if then the air were

meaning differing very materially from that of our author in the above paragraph; who would shew rather that as every thing which is material must possess length, breadth, and thickness, these properties cannot exist without the occupation of space, and as such, that even air which is invisible, and eludes the grasp, no less than the vision of the philosopher, may be so compressed as to attain a perfectly solid form. To illustrate experimentally the materiality of air it is merely necessary to invert a wine glass in a vessel of water, and the aeriform fluid within, will prevent the introduction of the water, which would enter immediately if the air was allowed to escape.

taken away, the bowl would go on without any friction, and consequently without any diminution of the velocity it had at setting out: and therefore, if the green were extended quite around the earth, the bowl would go on, round and round the earth, for ever.

If the bowl were carried several miles above the earth, and there projected in a horizontal direction, with such a velocity as would make it move more than a semidiameter of the earth, in the time it would take to fall to the earth by gravity; in that case, and if there were no resisting medium in the way, the bowl would not fall to the earth at all; but would continue to circulate round it, keeping always in the same tract, and returning to the same point from which it was projected, with the same velocity as at first. In this manner the moon goes round the earth, although she be as inactive and dead as any stone upon it.

Mobility.

The third property of matter is *mobility;* for we find that all matter is capable of being moved, if a sufficient degree of force be applied to overcome its inactivity or resistance.[2]

Divisibility.

The fourth property of matter is *divisibility,* of which there can be no end. For, since matter can never be annihilated by cutting or breaking, we can never imagine it to be cut into such small particles, but that if one of them be laid on a table, the uppermost side of it will be further from the table than the undermost side. More-

Note 2. Mobility is here very justly considered as a universal property of matter, and this law does not apply merely to matter in the abstract, as illustrations of its universality may be found in every part of created nature. Heat expands, and cold contracts the size of most bodies, and as we know from experience, that the temperature of the atmosphere is continually varying, it will be evident that the various particles with which it comes in contact must be in continual agitation. This then may be considered as one of the causes which tend to produce a species of perpetual motion upon the surface of the earth; the application of mechanical force which is more obvious will be treated of in a future page.

LECT. I. over, it would be absurd to say that the greatest mountain on earth has more halves, quarters, or tenth parts, than the smallest particle of matter has.

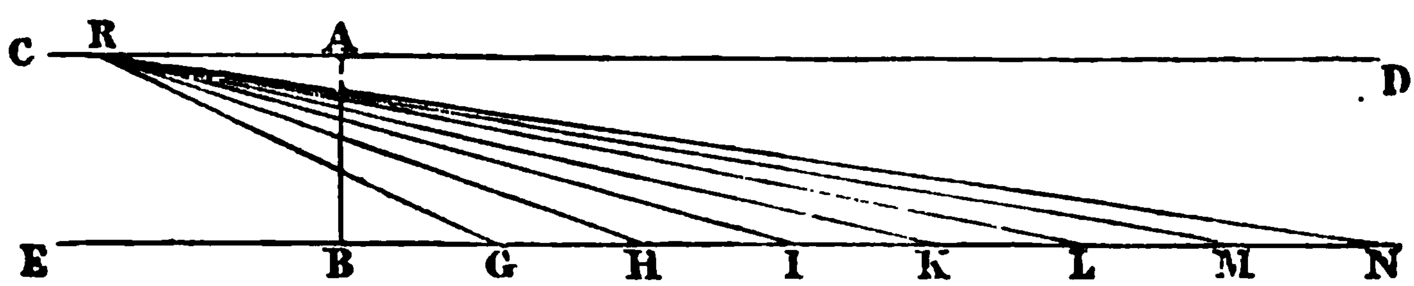
We have many surprising instances of the smallness to which matter can be divided by art: of which the two following are very remarkable.

1. If a pound of silver be melted with a single grain of gold, the gold will be equally diffused through the whole silver; so that, taking one grain from any part of the mass (in which there can be no more than the 5760th part of a grain of gold) and dissolving it in *aqua fortis*, the gold will fall to the bottom.

2. The gold beaters can extend a grain of gold into a leaf containing fifty square inches; and this leaf may be divided into 500000 visible parts. For an inch in length can be divided into 100 parts, every one of which will be visible to the bare eye: consequently a square inch can be divided into 10000 and 50 square inches into 500000. And if one of these parts be viewed with a microscope that magnifies the diameter of an object only 10 times, it will magnify the area 100 times; and then the 100th part of a 500000th part of a grain (that is, the 50 millionth part) will be visible. Such leaves are commonly used in gilding; and they are so very thin, that if 124500 of them were laid upon one another, and pressed together, they would not exceed one inch in thickness.

Yet all this is nothing in comparison of the lengths that nature goes in the division of matter. For Mr. *Leewenhoek* tells, us that there are more animals in the milt of a single cod-fish, than there are men upon the whole earth: and that, by comparing these animals in a microscope with grains of common sand, it appeared that one single grain is bigger than four millions of them. Now each animal must have a heart, arteries, veins, muscles, and nerves, otherwise it could neither live nor move. How inconceivably small then must the par-

ticles of their blood be, to circulate through the smallest ramifications and joinings of their arteries and veins. It has been found by calculation, that a particle of their blood must be as much smaller than a globe of the tenth part of an inch in diameter, as that globe is smaller than the whole earth; and yet if these particles be compared with the particles of light they will be found to exceed them as much in bulk as mountains do single grains of sand. For, the force of any body striking against an obstacle is directly in proportion to its quantity of matter multiplied into its velocity: and since the velocity of the particles of light is demonstrated to be at least a million times greater than the velocity of a cannon-ball, it is plain, that if a million of these particles were as big as a single grain of sand, we durst no more open our eyes to the light, that we durst expose them to sand shot point-blank from a cannon.[3]



That matter is infinitely divisible, in a mathematical sense, is easy to be demonstrated. For let *A B* be the length of a particle to be divided; and let it be touched

Note 3. Some additional illustrations may readily be afforded of the chemical as well as the mechanical division of matter: —Thus, if we take a grain of copper, and dissolve it in diluted nitric acid (*aqua-fortis* and water) the smallest drop will readily coat the surface of a table knife with that metal. A nearly similar though a more simple mode of dividing a body by solution may also be employed. If a grain of cochineal or common blue, be mixed with three gallons of water, it will be found, that each drop of the fluid mixture will have imbibed a portion of the colouring matter equal to about one hundred and thirty-thousandth part of a grain. *Mica* or talc affords some very wonderful instances of the mechanical division of matter. A block of less than an inch in thickness, having been known to furnish more than one million distinct plates. Our author speaks of the amazing extension

at opposite ends by the parallel lines *C D* and *E N* which suppose to be infinitely extended beyond *D* and *N*. Set off the equal divisions, *B G*, *G H*, *H I*, &c. on the line *E N*, towards the right hand from *B*; and take a point, as at *R*, any where towards the left hand from *A*, in the line *C D*: Then from this point, draw the right lines *R G*, *R H*, *R I*, &c. each of which will cut off a part from the particle *A B*. But after any finite number of such lines are drawn, there will still remain a part, as *A P*, at the top of the particle, which can never be cut off: because the lines *D R* and *E F* being parallel, no line can ever be drawn from the point *R* to any point of the line *E F* that will coincide with the line *R D*. Therefore the particle *A B* contains more than any finite number of parts.

A fifth property of matter is *attraction*, which seems rather to be infused than inherent. Of this there are four kinds, viz. *cohesion*, *gravitation*, *magnetism*, and *electricity*.

Cohesion. The *attraction of cohesion*, is that by which the small parts of matter are made to stick and cohere together. Of this we have several instances: some of which follow.

1. If a small glass tube open at both ends, be dipped in water, the water will rise up in the tube to a considerable height above its level in the basin: which must be owing to the attraction of a ring of particles of the glass all around in the tube, immediately above those to which the water at any instant rises. And when it has risen so high, that the weight of the column balances the attraction of the tube, it rises no higher.[4] This can be no

of a single grain of gold by beating, but wonderful as this may appear, it can in no shape be compared with the micrometer wires lately drawn by Dr. Wollaston, which have been obtained as small as the thirty thousandth part of an inch in diameter.

Note 4. If a series of glass tubes, varying in size, be employed instead of the one here alluded to, the experiment will be materially improved, as it may then experimentally shewn that the height of

ways owing to the pressure of the air upon the water in the basin; for as the tube is open at top, it is full of air above the water, which will press as much upon the water in the tube as the neighbouring air does upon any column of an equal diameter in the basin. Besides, if the same experiment be made in an exhausted receiver of the air-pump, there will be found no difference.[5]

2. A piece of loaf-sugar will draw up a fluid, and a sponge will draw in water: and on the same principle sap ascends in trees.

3. If two drops of quicksilver be placed near each other, they will run together and become one large drop.[6]

4. If two pieces of lead be scraped clean, and pressed together with a twist, they will attract each other so

the column of water depends principally on the internal diameter of the tube. Glass canes, admirably adapted for the illustration of this fact, may be procured at the glass-houses for a few pence, and as they are seldom drawn of one size throughout, a single cane may be divided into short lengths for the purpose.—A very beautiful mathematical figure may also be formed, by connecting two plates of flat glass in such a way as to represent the two covers of a book partly opened; the edges being accurately in contact at the one side, whilst the opposite side of the plates are held asunder by a thin wedge. The plates thus united, should be placed erect in a shallow trough of coloured water, and in a few moments a curved line will be formed called an hyperbola. It may be proper to state, that the figure is more immediately formed, if an essential oil is substituted for the coloured water.

Note 5. The ascent of fluids in capillary tubes, has been applied to the construction of a common filter, and the advantage it possesses over a downward filter, arises from the facility with which the sediment may be separated from the clear fluid, which in the ordinary mode of filtration tends to choke the apparatus.

Note 6. A reference to the same cause will readily account for the spherical form assumed by drops of falling rain, as well as a variety of other meteorological phenomena: a popular poet has very beautifully remarked, that

"That very law which moulds a tear,
And bids it trickle from its source,
That law preserves the earth a sphere,
And guides the planets in their course."

LECT. I. strongly, as to require a force much greater than their own weight to separate them. And this cannot be owing to the pressure of the air, for the same thing will hold in an exhausted receiver.

5. If two polished plates of marble or brass be put together, with a little oil between them, to fill up the pores in their surfaces, and prevent the lodgement of any air, they will cohere so strongly, even if suspended in an exhausted receiver, that the weight of the lower plate will not be able to separate it from the upper one. In putting these plates together, the one should be rubbed upon the other, as a joiner does two pieces of wood when he glues them.

6. If two pieces of cork, equal in weight, be put near each other in a basin of water, they will move equally fast toward each other with an accelerated notion, until they meet: and then, if either of them be moved, it will draw the other after it. If two corks of unequal weights be placed near each other, they will approach with accelerated velocities inversely proportioned to their weights: that is, the lighter cork will move as much faster than the heavier, as the heavier exceeds the lighter in weight. This shews that the attraction of each cork is in direct proportion to its weight, or quantity of matter.

This kind of attraction reaches but to a very small distance; for, if two drops of quicksilver be rolled in dust, they will not run together, because the particles of dust keep them out of the sphere of each other's attraction.[7]

Note 7. This experiment may be shewn more perfectly, if the seeds of lycopodium be employed; as the fluid rings, which really produce the effects described in the preceding paragraph are not in this case allowed to operate. The seed already alluded to may be strewed upon a table, and water poured over its surface, without wetting the wood beneath.

Where the sphere of attraction ends, a *repulsive force* begins; thus, water repels most bodies till they are wet; and hence it is, that a small needle, if dry, swims upon water, and flies walk upon it without wetting their feet.[8] — Repulsion.

The repelling force of the particles of a fluid is but small; and therefore, if a fluid be divided, it easily unites again. But if glass, or any other hard substance, be broken into small parts, they cannot be made to stick together again without being first wetted; the repulsion being too great to admit of a re-union.

The repelling force between water and oil is so great, that we find it almost impossible to mix them so as not to separate again. If a ball of light wood be dipped in oil, and then put into water, the water will recede so as to form a channel of some depth all around the ball.

The repulsive force of the particles of air is so great, that they can never be brought so near together by condensation as to make them stick, or cohere. Hence it is, that when the weight of the incumbent atmosphere is taken off from any small quantity of air, that quantity will diffuse itself so as to occupy (in comparison,) an infinitely greater portion of space than it did before.

Attraction of gravitation is that power by which — Gravitation.

Note 8. Although steel has a greater specific gravity than water, and, as such, being bulk for bulk heavier, must, under ordinary circumstances, sink in the fluid in which it is immersed, yet we find a variety of exceptions to this apparently self-evident law. By taking the two instances cited by our author, we may, however, sufficiently illustrate the matter. The floating of a steel wire is alluded to, as a proof of some repulsive force in the needle: that, however, is not the fact, as the phenomenon may readily be accounted for by reference to the cohesion existing between the particles of the water; which, being greater than the gravitating force of so light a body, admits of a partial hollow being formed without allowing the needle to sink. In the latter case cited, two causes appear to operate in supporting the various aquatic insects, which are seen passing upon the surface of the water without being actually immersed in it. The first will be found similar to that alluded to with reference to the needle; and the second is a very remarkable provision made by nature, apparently for the express purpose of supporting them upon their native element.

LECT. I. distant bodies tend towards one another. Of this we have daily instances, in the falling of bodies to the earth. By this power in the earth it is, that bodies, on whatever side, fall in lines perpendicular to its surface; and consequently, on opposite sides they fall in opposite directions; all towards the center, where the force of gravity is as it were accumulated: and by this power it is, that bodies on the earth's surface are kept to it on all sides, so that they cannot fall from it. And as it acts upon all bodies in proportion to their respective quantities of matter, without any regard to their bulks or figures, it accordingly constitutes their weight. Hence,

If two bodies, which contain equal quantities of matter, were placed at ever so great a distance from one another, and then left at liberty in free space; if there were no other bodies in the universe to affect them, they would fall equally swift towards one another by the power of gravity, with velocities accelerated as they approached each other; and would meet in a point which was half way between them at first. Or, if two bodies, containing unequal quantities of matter, were placed at any distance, and left in the same manner at liberty, they would fall towards one another with velocities which would be in an inverse proportion to their respective quantities of matter; and moving faster and faster in their mutual approach, would at last meet in a point as much nearer to the place from which the heavier body began to fall, than to the place from which the lighter body began to fall, as the quantity of matter in the former exceeded that in the latter.

All bodies that we know of have gravity or weight. For, that there is no such thing as positive levity, even in smoke, vapours, and fumes, is demonstrable by experiments on the air-pump; which shews, that although the smoke of a candle ascends to the top of a tall receiver when full of air, yet, upon the air's being exhausted out of the receiver, the smoke falls down to

the bottom of it. So, if a piece of wood be immersed in a jar of water, the wood will rise to the top of the water, because it has a less degree of weight than its bulk of water has: but if the jar be emptied of water, the wood falls to the bottom.[9]

Gravity demonstrated to be as the quantity of matter in bodies.

As every particle of matter has its proper gravity, the effect of the whole must be in proportion to the number of the attracting particles; that is, as the quantity of matter in the whole body. This is demonstrable by experiments on pendulums; for, if they are of equal lengths, whatever their weights be, they vibrate in equal times. Now it is plain, that if one be double or triple the weight of another, it must require a double or triple power of gravity to make it move with the same celerity: just as it would require a double or triple force to project a bullet of twenty or thirty pounds weight with the same degree of swiftness that a bullet of ten pounds would require. Hence it is evident, that the power or force of gravity is always proportional to the quantity of matter in bodies, whatever their bulks or figures are.

It decreases as the square of the distance increases.

Gravity also, like all other virtues or emanations which proceed or issue from a center, decreases as the distance multiplied by itself increases: that is, a body at twice the distance of another, attracts with only a fourth part of the force; at thrice the distance, with a ninth part; at four times the distance, with a sixteenth part; and so on. This too is confirmed by comparing the distance which the moon falls in a minute, from a right line touching her orbit, and the distance through which heavy bodies near the earth fall in that time.

Note 9. The floating of wood in water is here shewn to be analogous to that of smoke in the air, but a still more striking illustration of the buoyant power of air will be found in the ascent of a balloon, the weight of which frequently exceeds from three to five hundred pounds in weight; and we shall presently find, that there are other bodies much lighter than the gas or air with which balloons are usually inflated.

LECT. I. And also by comparing the forces which retain Jupiter's moons in their orbits, with their respective distances from Jupiter. These forces will be explained in the next Lecture.

The velocity which bodies near the earth acquire in descending freely by the force of gravity, is proportional to the times of their descent. For, as the power of gravity does not consist in a single impulse, but is always operating in a constant and uniform manner, it must produce equal effects in equal times; and consequently in a double or triple time, a double or triple effect. And so, by acting uniformly on the body, must accelerate its motion proportionably to the time of its descent.

To be a little more particular on this subject, let us suppose that a body begins to move with a celerity constantly and gradually increasing, in such a manner, as would carry it through a mile in a minute; at the end of this space it will have acquired such a degree of celerity, as is sufficient to carry it two miles the next minute, though it should then receive no new impulse from the cause by which its motion had been accelerated: but if the same accelerating cause continues, it will carry the body a mile further; on which account, it will have run through four miles at the end of two minutes; and then it will have acquired such a degree of celerity as is sufficient to carry it through a double space in as much more time, or eight miles in two minutes, even though the accelerating force should act upon it no more. But this force still continuing to operate in a uniform manner, will again, in an equal time, produce an equal effect; and so, by carrying it a mile further, cause it to move through five miles the third minute: for, the celerity already acquired, and the celerity still acquiring, will have each its complete effect. Hence we learn, that if the body should move one mile the first minute, it would move three miles the second, five the third,

LECT. I.

seven the fourth, nine the fifth, and so on in proportion. And thus it appears, that the spaces described in successive equal parts of time, by an uniformly accelerated motion, are always as the odd numbers, 1, 3, 5, 7, 9, &c. and consequently, the whole spaces are as the squares of the times, or of the last acquired velocities.

For, the continued addition of the odd numbers yields the squares of all numbers from unity upwards. Thus, 1 is the first odd number, and the square of 1 is 1; 3 is the second odd number, and this added to 1 makes 4, the square of 2; 5 is the third odd number, which added to 4 makes 9, the square of 3; and so on for ever. Since, therefore, the times and velocities proceed evenly and constantly as 1, 2, 3, 4, &c. but the spaces described by each in equal times, are as 1, 3, 5, 7, &c. it is evident that the space described

In one minute will be . . . . 1=square of 1
In 2 minutes . . . . . 1+3=4=square of 2
In 3 minutes . . . . 1+3+5=9=square of 3
In 4 minutes . 1+3+5+7=16=square of 4, &c.[10]

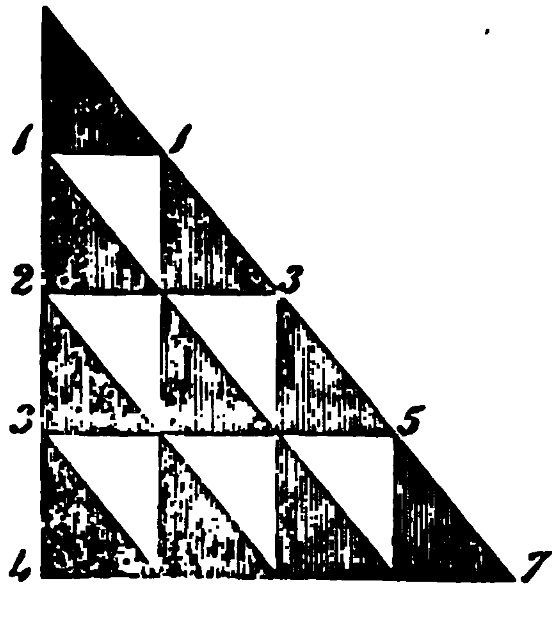
N. B. The character + signifies *more*, and = *equal*.

The descending velocity will give a power of equal ascent.

As heavy bodies are uniformly accelerated by the power of gravity in their descent, it is plain that they must be uniformly retarded by the same power in their

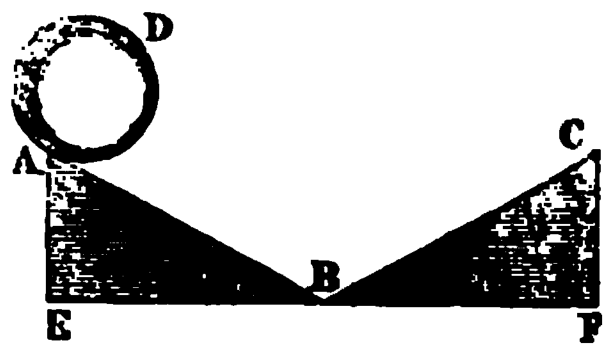
Note 10. A very beautiful illustration of the doctrine of accelerated motion may be furnished by a reference to a geometrical figure.

The perpendicular row of figures in the triangle represent equal portions of time, during which, the body may be supposed to fall from the highest point. The smaller triangles represent the number of feet the body would pass through in any given period from one to four seconds. In the first we find it would have passed through but one foot, in the second through three feet, in the third through five feet, and in the last through seven feet.



LECT II. ascent. Therefore, the velocity which a body acquires by falling, is sufficient to carry it up again to the same height from whence it fell: allowance being made for the resistance of the air, or other medium in which the body is moved.

Thus, the body *D* in rolling down the inclined plane *A B* will acquire such a velocity by the time it arrives at *B*, as will carry it up the inclined plane *B C*, almost to *C*; and would carry it quite up to *C*, if the body and plane were perfectly smooth, and the air gave no resistance.—So, if a pendulum were put into motion in a space quite free of air, and all other resistance, and had no friction on the point of suspension, it would move for ever: for the velocity it had acquired in falling through the descending parts of the arc, would be still sufficient to carry it equally high in the ascending part thereof.



Center of gravity. The *center of gravity* is that point of a body in which the whole force of its gravity or weight is united. Therefore, whatever supports that point bears the weight of the whole body: and whilst it is supported, the body cannot fall; because all its parts are in a perfect equilibrium about that point.

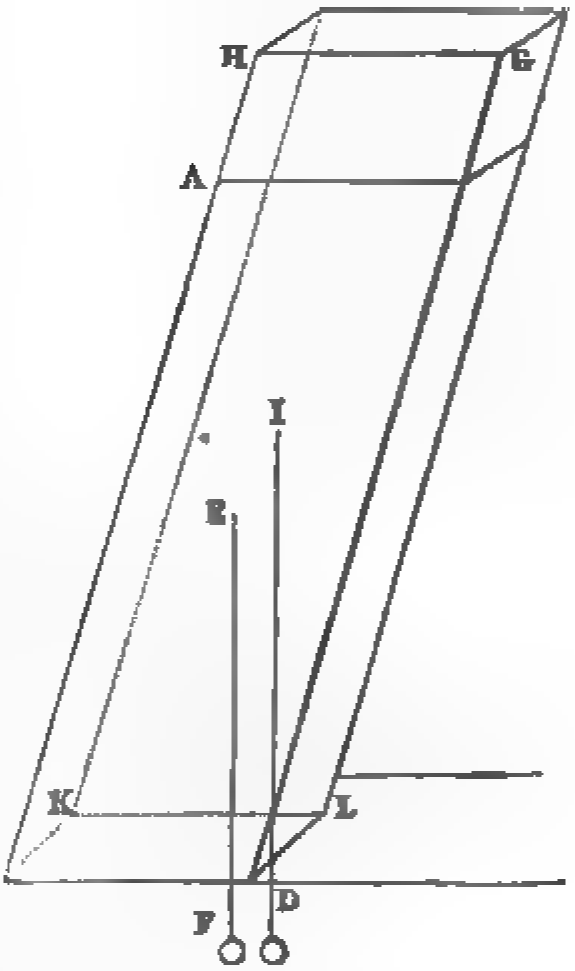
and line of direction. An imaginary line drawn from the center of gravity of any body towards the center of the earth, is called the *line of direction*. In this line all heavy bodies descend, if not obstructed.

Since the whole weight of a body is united in its

In the above illustration, we have, for the sake of simplicity, supposed that the body would pass through but one foot in the first second, this however, is not the fact, as any heavy body in that period of time, would have passed through about sixteen feet, and continue to increase in the same ratio. The rule therefore is to multiply the square of the time by sixteen, which will give the entire number of feet through which the body has fallen.

of gravity as that center ascends or descends, LECT. I.
ıst look upon the whole body to do so too. But
s contrary to the nature of heavy bodies to ascend
ir own accord, or not to descend when they are
tted; we may be sure, that unless the center of
y be supported, the whole body will tumble or fall.[11]
: it is, that bodies stand upon their bases when the
f direction falls within the base; for in this case
ıdy cannot be made to fall without first raising the
· of gravity higher than it was before.

ıs, the inclining
A D, whose cen-
f gravity is *E*,
ı firmly on its
D *K*, because the
f direction *E F*
within the base.
f a weight, as
H, be laid upon
ıp of the body,
nter of gravity of
hole body and
t together is rais-
to *I*; and then,
ɜ line of direc-
I D falls with-
e base at *D*, the
· of gravity, *I* is
ıpported and the
body and weight tumble down together.

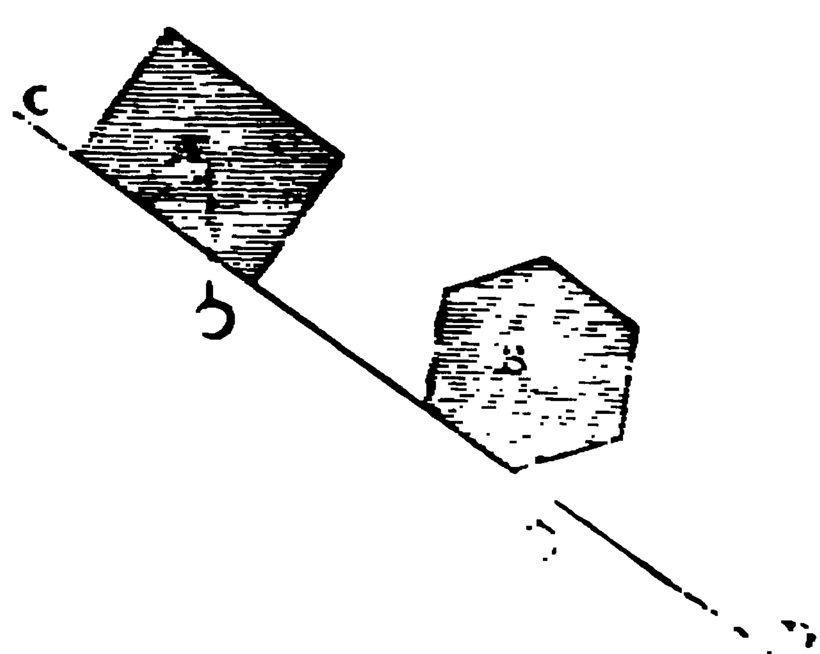


11. There are two apparent exceptions to the general law o.
tion, which it may be proper to notice on the present occasion.
these is well known, and is called the *hanging tower of Pisa*—
er is a nearly similar building at Caerphilly in Glamorganshire.
e two towers, the one leans twelve feet from the perpendicular
· other nearly fifteen, but as in both cases the center of gravity
ı the base, no danger of their falling need be apprehended.
he materials retain their cohesive power.

[illegible] hastily [illegible] for by [illegible] far as to [illegible] and if they [illegible] Whereas, had [illegible] have brought [illegible] center of [illegible] means [illegible]

The [illegible] line of [illegible] the more [illegible] the nar- [illegible] is to [illegible] be over- [illegible] sufficient to re- [illegible] the latter [illegible] that a sphere [illegible] and that it is [illegible] things which are [illegible] point.—From [illegible] the plane [illegible] the body [illegible] direction [illegible] roll down [illegible] Thus, the body *A* [illegible] inclined plane *C D*, whilst the body *B* rolls down upon it.

When the line of direction falls within the base of our feet, we stand; and most firmly when it is in the middle: but when it is out of that base, we immediately fall. And



is not only pleasing, but even sur-

prising, to reflect upon the various and unthought of methods and postures which we use to retain this position, or to recover it when it is lost. For this purpose we bend our body forward when we rise from a chair, or when we go up stairs: and for this purpose a man leans forward when he carries a burden on his back, and backward when he carries it on his breast; and to the right or left side as he carries it on the opposite side. A thousand more instances might be added.[12]

The quantity of matter in all bodies is in exact proportion to their weights, bulk for bulk. Therefore, heavy bodies are as much more dense or compact than light bodies of the same bulk, as they exceed them in weight.

All bodies porous.

All bodies are full of pores, or spaces void of matter: and in gold, which is the heaviest of all known bodies, there is perhaps a greater quantity of space than of matter. For the particles of heat and magnetism find an easy passage through the pores of gold; and even water itself has been forced through them. Besides, if we consider how easily the rays of light pass through so solid a body as glass, in all manner of directions, we shall find reason to believe that bodies are much more porous than is generally imagined.[13]

Note 12. Rope dancers and tumblers maintain a species of tottering equilibrium by means of a long pole, which being rapidly shifted in any required direction, retains the center of gravity of the whole body within the toe.

Note 13. Without attempting to assert, with a distinguished philosopher, that the whole of created nature may be compressed into the size of a nut-shell; we may at least pause for a moment to examine the amazing porosity of some bodies, which would at first view appear perfectly dense and solid. Thus we find that glass, though of great specific gravity, is readily penetrated by the sun's rays, when conveyed to a focus by means of a burning glass; and the light of a candle may be seen through a thin leaf of gold. To further illustrate the matter, we may suppose a body to be so constructed as to have as much vacuity as matter, and as such, half the body vacuous.

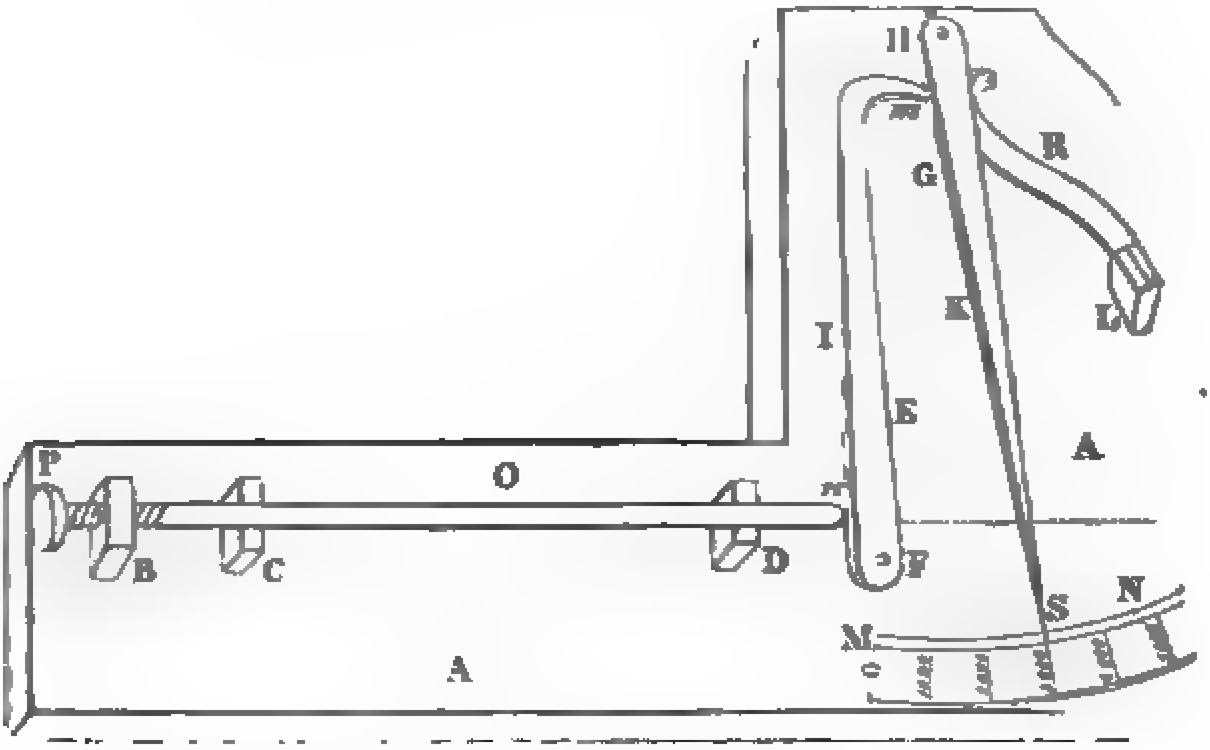
LECT. II.

The expansion of metals.

All bodies are some way or other affected by heat; and all metallic bodies are expanded in length, breadth, and thickness thereby.—The proportion of the expansion of several metals, according to the best experiments I have been able to make with my pyrometer, is nearly thus: Iron and steel as 3, copper 4 and a half, brass 5, tin 6, lead 7. An iron rod 3 feet long is about one 70th part of an inch longer in summer than in winter.

The pyrometer

The pyrometer here mentioned being (for aught I know) of a new construction, a description of it may perhaps be agreeable to the reader.



A A is a flat piece of mahogany, in which are fixed

If the particles of which the body is actually formed, be constructed in the same manner; then the vacuity will become three-fourths of the space occupied by the body. Carrying the supposition still further, we may suppose the last mentioned particles constructed in the same manner, the vacuity will then be seven-eighths; and if the series be carried forward to the tenth order of particles, the vacuity will exceed the matter one thousand and twenty-three times. A very obvious illustration of the effects of caloric in producing porosity is shewn in the formation of vesicular vapour or steam, which may be increased to many thousand times its original bulk, by an increase of temperature.

four brass studs *B, C, D, L*; and two pins, one at *F* and the other at *H*. On the pin *F* turns the crooked index *E I*, and upon the pin *H* the straight index *G K*, against which a piece of watch-spring *R* bears gently, and so presses it towards the beginning of the scale *M N*, over which the point of that index moves. This scale is divided into inches and tenth parts of an inch: the first inch is marked 1000, the second 2000, and so on. A bar of metal *O* is laid into notches in the top of the studs *C* and *D*; one end of the bar bearing against the adjusting screw *P*, and the other end against the crooked index *E I*, at a 20th part of its length from its center of motion *F*.—Now it is plain, that however much the bar *O* lengthens, it will move that part of the index *E I*, against which it bears, just as far: but the crooked end of the same index, near *H*, being 20 times as far from the center of motion *F* as the point is against which the bar bears, it will move 20 times as far as the bar lengthens. And as this crooked end bears against the index *G K* at only a 20th part of the whole length *G S* from its center of motion *H*, the point *S* will move through 20 times the space that the point of bearing near *H* does. Hence, as 20 multiplied by 20 produces 400, it is evident that if the bar lengthens but a 400th part of an inch, the point *S* will move a whole inch on the scale; and as every inch is divided into 10 equal parts, if the bar lengthen but the 10th part of the 400th part of an inch, which is only the 4000th part of an inch, the point *S* will move the tenth part of an inch, which is very perceptible.

To find how much a bar lengthens by heat, first lay it cold into the notches of the studs, and turn the adjusting screw *P* until the spring *R* brings the point *S* of the index *G K* to the beginning of the divisions of the scale at *M*: then, without altering the screw any farther, take off the bar and rub it with a dry

LECT. I. woollen cloth till it feels warm; and then, laying it on where it was, observe how far it pushes the point *S* upon the scale by means of the crooked index *E I*; and the point *S* will shew exactly how much the bar has lengthened by the heat of rubbing. As the bar cools, the spring *R* bearing against the index *K G*, will cause its point *S* to move gradually back towards *M* in the scale: and when the bar is quite cold, the index will rest at *M*, where it was before the bar was made warm by rubbing The indexes have small rollers under them at *I* and *K*; which, by turning round on the smooth wood as the indexes move, make their motions the easier, by taking off a great part of the friction, which would otherwise be on the pins *F* and *H*, and of the points of the indexes themselves on the wood.[14]

Magnetism. Besides the universal properties above mentioned, there are bodies which have properties peculiar to themselves: such as the loadstone, in which the most remarkable are these: 1. It attracts iron and steel only[15]

Note 14. The pyrometer here described, has been justly considered as defective both in principle and execution. If it be merely intended to illustrate the expansion of metals by heat, the fact may be shewn by fitting a piece of large wire into a hole, and it will be found that after it has been brought to a red heat, that its bulk will have so far increased, as to prevent its passing through an aperture. A reference to this circumstance will serve to account for the change of form which takes place in bridges and other edifices constructed of iron. When it is found necessary however, to ascertain the comparative amount of expansion in various metals under the same degree of temperature, a variety of more accurate instruments may be resorted to: one of these will be described in a future page.

Note 15. For *iron* and *steel*, we may here substitute ferruginous bodies generally, as subsequent experiments have shewn that there is scarcely any body that is not operated on by the magnet. To discover the amount of attraction in substances but very slightly magnetic, it is necessary to employ a paper or cork float in a vessel of water, and upon this the body under examination should be placed so as to prevent the water wetting its upper surface, and the relative distance, at which this is acted upon, in proportion to its bulk, determines the magnetic power.

2. It constantly turns one of its sides to the north and another to the south, when suspended to a thread that does not twist. 3. It communicates all its properties to a piece of steel when rubbed upon it, without losing any itself.

According to Dr. *Helsham's* experiments, the attraction of the loadstone decreases as the square of the distance increases. Thus, if a loadstone be suspended at one end of a balance, and counterpoised by weights at the other end, and a flat piece of iron be placed beneath it, at the distance of four tenths of an inch, the stone will immediately descend and adhere to the iron. But if the stone be again removed to the same distance, and as many grains be put into the scale at the other end as will exactly counterbalance the attraction, then, if the iron be brought twice as near the stone as before, that is, only two tenth parts of an inch from it, there must be four times as many grains put into the scale as before, in order to be a just counterbalance to the attractive force, or to hinder the stone from descending and adhering to the iron. So, if four grains will do in the former case, there must be sixteen in the latter. But from some later experiments, made with the greatest accuracy, it is found that the force of magnetism decreases in a ratio between the reciprocal of the square, and the reciprocal of the cube of the dis-

If this precaution be observed, the following substances will be found to possess magnetic properties. All the metallic ores, amongst which we particularly enumerate iron, cobalt, zinc, and bismuth. The calcareous are the least attractable of the earths, whilst the siliceous are the most frequently attracted. Amongst the precious stones possessing this property, we may place the emerald, the ruby, the tourmaline, and the garnet: the last of which frequently acquires permanent magnetism, which may be accounted for by reference to the large proportion of iron it contains. It may be proper to add, that Dr. Young found a single grain of iron sufficient to make twenty pounds of another metal perceptibly magnetic.

Lect. I. times; approaching to the one or the other, as the magnitudes of the attracting bodies are varied.

Electricity. Several bodies, particularly amber, glass, jet, sealing-wax, agate, and almost all precious stones, have a peculiar property of attracting and repelling light bodies when heated by rubbing. This is called *electrical attraction*, in which the chief things to be observed are, 1. If a glass tube about an inch and a half diameter, and two or three feet long, be heated by rubbing, it will alternately attract and repel all light bodies when held near them. 2. It does not attract by being heated without rubbing. 3. Any light body being once repelled by the tube, will never be attracted again till it has touched some other body. 4. If the tube be rubbed by a moist hand, or any thing that is wet, it totally destroys the electricity. 5. Any body, except air, being interposed, stops the electricity. 6. The tube attracts stronger when rubbed over with bees-wax, and then with a dry woollen-cloth. 7. When it is well rubbed, if a finger be brought near it, at about the distance of half an inch, the effluvia will snap against the finger, and make a little crackling noise: and if this be performed in a dark place, there will appear a little flash of light.[16]

As the expansion of metals by heat was but briefly examined at *page* 18, it has been deemed advisable to reserve the following valuable table for the end of the Lecture. It shews, in parts of an inch, how much one foot length of different substances is expanded by 180° of heat, Fahrenheit's scale,) between the freezing and the boiling points of water. To the first seven substances, (which were examined in Mr. Ramsden's most accurate pyrometer,) there are added the expansions for a single degree of heat. The others were determined by Mr. Smeaton with his pyrometer.

Note 16. See Ferguson's Introduction to Electricity, with notes, &c. now preparing for publication.

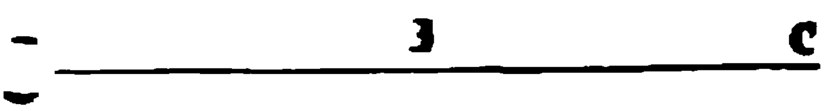
LECT. I.

	Fahrenheit's Scale. By 1°	Fahrenheit's Scale. By 180°.
Standard brass scale, supposed to be Hamburgh brass	0.0001237	0.0222646
English plate brass in form of a rod	0.0001262	0.0227136
English plate brass in form of a trough	0.0001263	0.0227386
Steel rod	0.0000763	0.0137368
Cast-iron prism	0.0000740	0 0133126
Glass tube	0.0000517	0.0093138
Solid glass rod	0.0000539	0.0096944
White glass barometer tube		0.0100
Martial regulus of antimony		0.0130
Blistered steel		0.0138
Hard steel		0.0147
Iron		0.0151
Bismuth		0.0167
Copper hammered		0.0204
Copper eight parts, with tin one part		0.0218
Cast brass		0.0225
Brass sixteen parts, with tin one part		0.0229
Brass wire		0.0232
Speculum metal		0.0232
Spelter solder, *viz.* brass two parts, zinc one		0.0247
Fine pewter		0.0274
Grain tin		0.0298
Soft solder, *viz.* lead two parts, tin one		0.0301
Zinc eight parts, with tin one, a little hammered		0.0323
Lead		0.0344
Zinc or spelter		0.0353
Zinc hammered half an inch *per* foot		0.0373

LETTER I.

OF CENTRAL FORCES.[17]

[illegible] W[illegible] is a necessary consequence [illegible] inactivity of matter [illegible] continue in the state [illegible].



[illegible] any part [illegible] either draws or impels [illegible] for ever remain in that part of space [illegible] have no tendency of itself to [illegible]. If it receives a single impulse [illegible] from A towards B, it will go on in that direction [illegible] itself. It could never [illegible] line, nor stop its course.— When it has gone through the space A B, and met with no resistance, its velocity will be the same at B as it was at A, and this velocity, in as much more time, will carry it through as much more space, from B to C; and so on for ever. Therefore, when we see a body in motion, we conclude that some other substance must have given it that motion; and when we see a body fall from motion to rest, we conclude that some other body or cause stopped it.

All motion naturally rectilineal.

As all motion is naturally rectilineal, it appears, that a bullet projected by the hand, or shot from a cannon, would for ever continue to move in the same direction it received at first, if no other power diverted its course.[18]

Note 17. Every body moved in a circle, has a tendency to fly off from its centre, which is called the centrifugal force, and it is opposed to the centripetal or gravitating force, which invariably draws a body towards the nearest or greatest mass that occurs within its sphere of operation. These two forces are called *central forces*.

Note 18. The art of gunnery depends principally on a due attention to the projectile and gravitating forces, operating on the body to

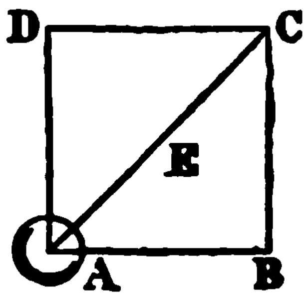
Therefore, when we see a body move in a curve of any kind whatever, we conclude it must be acted upon by two powers at least; one putting it in motion, and another drawing it off from the rectilineal course it would otherwise have continued to move in: and whenever that power which bent the motion of the body from a straight line into a curve, ceases to act, the body will again move on in a straight line touching that point of the curve in which it was when the action of that power ceased. For example, a pebble moved round in a sling ever so long a time, will fly off the moment it is set at liberty, by slipping one end of the sling cord: and will go on in a line touching the circle it described before: which line would actually be a straight one, if the earth's attraction did not affect the pebble, and bring it down to the ground. This shews that the natural tendency of the pebble, when put into motion, is to continue moving in a straight line, although by the force that moves the sling it be made to revolve in a circle.

The effects of combined forces.

The change of motion produced is in proportion to the force impressed: for the effects of natural causes are always proportionate to the force or power of those causes.

By these laws it is easy to prove that a body will describe the diagonal of a square or parallelogram, by two forces conjoined, in the same time that it would describe either of the sides, by one force singly.

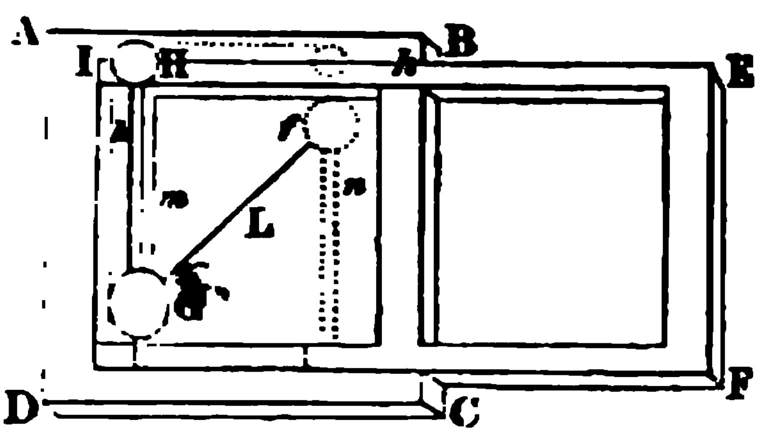
Thus, suppose the body A to represent a ship at sea; and that it is driven by the wind, in the right line $A\ B$, with such a force as would carry it uniformly from A to B in a minute: then, suppose a stream or currrent of water running in the direction $A\ D$, with



be impelled. If a bullet be fired from the mouth of a cannon, its path will be a parabola, as the effect produced by the powder will continually diminish, while the tendency to descend, must of necessity increase with the diminished projectile force.

LECT. II.

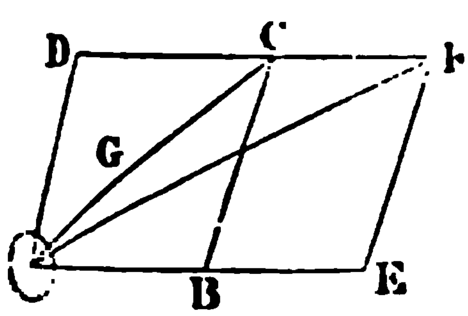
such a force as would carry the ship through an equal space from *A* to *D* in a minute. By these two forces, acting together at right angles to each other, the ship will describe the line *A E C* in a minute: which line (because the forces are equal and perpendicular to each other) will be the diagonal of an exact square.



To confirm this law by an experiment, let there be a wooden square *A B C D* so contrived, as to have the part *B E F C* made to draw out or push into the square at pleasure. To this part let the pulley *H* be joined, so as to turn freely on an axis, which will be at *H* when the piece is pushed in, and at *h* when it is drawn out. To this part let the ends of a straight wire *k* be fixed, so as to move along with it, under the pulley: and let the ball *G* be made to slide easily on the wire. A thread *m* is fixed to this ball, and goes over the pulley to *I*; by this thread the ball may be drawn up on the wire, parallel to the side *A D*, when the part *B E F C* is pushed as far as it will go into the square. But, if this part be drawn out, it will carry the ball along with it, parallel to the bottom of the square *D C*. By this means the ball *G* may either be drawn perpendicularly upward by pulling the thread *m*, or moved horizontally along by pulling out the part *B E F C*, in equal times, and through equal spaces; each power acting equally and separately upon it. But if, when the ball is at *G*, the upper end of the thread be tied to the pin *I*, in the corner *A* of the fixed square, and the moveable part *B E F G* be drawn out, the ball will then be acted upon by both the powers together: for it will be drawn up by the thread towards the top of the square, and at the same time carried with its wire *k*

towards the right hand *B C*, moving all the while in the diagonal line *L*; and will be found at *g* when the sliding part is drawn out as far as it was before; which then will have caused the thread to draw up the ball to the top of the inside of the square, just as high as it was before, when drawn up singly by the thread without moving the sliding part.

If the acting forces are equal, but at oblique angles to each other, so will the sides of the parallelogram be: and the diagonal run through by the moving body will be longer or shorter, according as the obliquity is greater or smaller. Thus, if two equal forces act conjointly



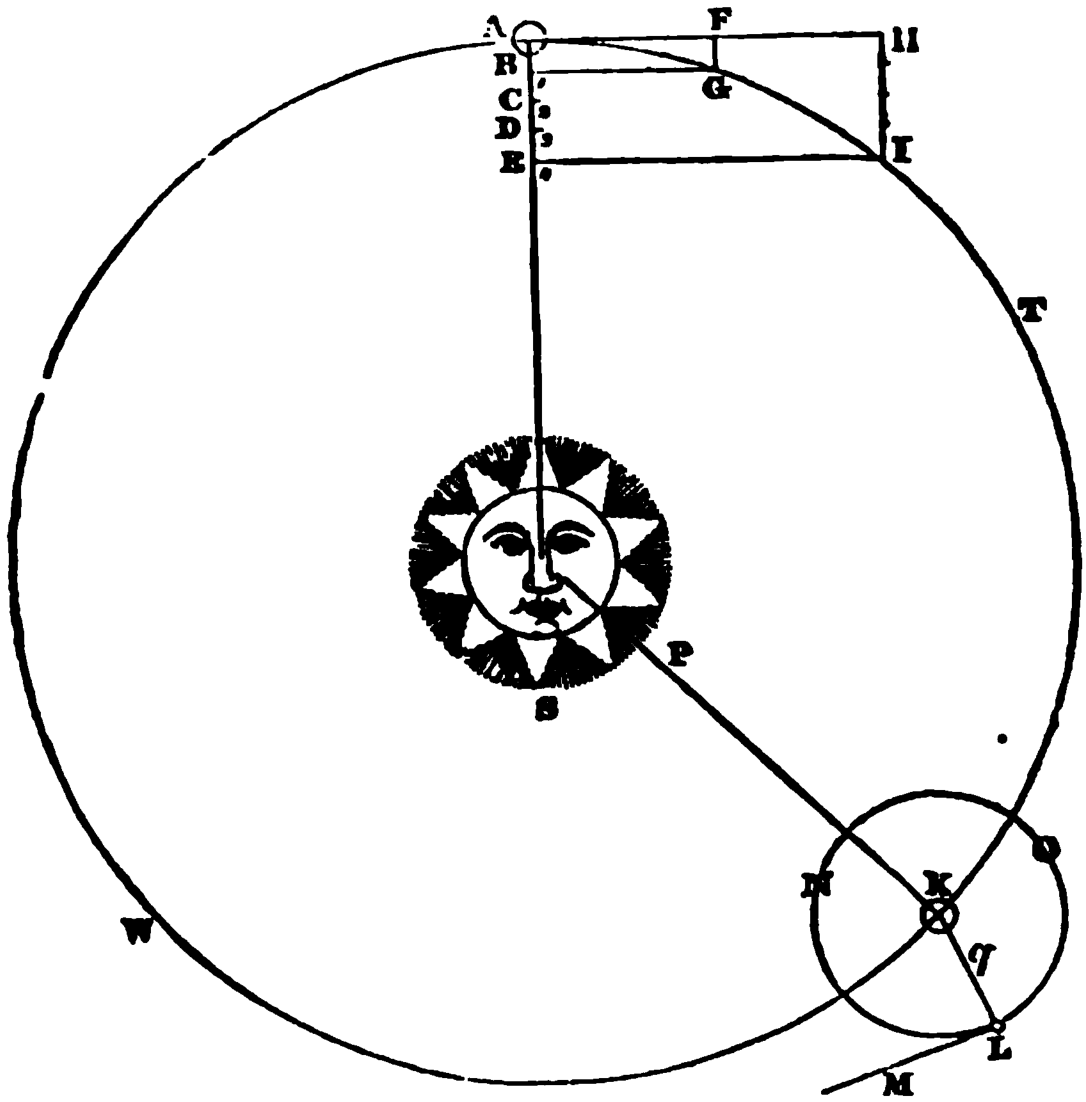
upon a ball or any other body, one having a tendency to move it towards *B* in the same time that the other has a tendency to move through an equal space towards *D*; it will describe a diagonal line in the same time that either of the single forces would have caused it to describe either of the sides. If one of the forces be greater than the other, then one side of the parallelogram will be so much longer than the other. For, if one force singly would carry the body through the space towards *E*, in the same time that the other would have carried it through the space towards *D*, the joint action of both will carry it in the same time through the space to *F*, which is the diagonal of the oblique parallelogram.

If both forces act upon the body in such a manner, as to move it uniformly, the diagonal described will be a straight line; but if one of the forces acts in such a manner as to make the body move faster and faster, then the line described will be a curve. And this is the case of all bodies which are projected in rectilineal directions, and at the same time acted upon by the power of gravity; which has a constant tendency to accelerate their motions in the direction wherein it acts.

LECT. II.

The laws of the planetary motions.

From the uniform projectile motion of bodies in straight lines, and the universal power of gravity or attraction, arises the curvilineal motion of all the heavenly bodies. If the body *A* be projected along the straight line *A F H* in open space, where it meets with no resist-



ance, and is not drawn aside by any power, it will go on for ever with the same velocity, and in the same direction. But if, at the same moment, the projectile force is given it at *A*, the body *S* begins to attract it with a force duly adjusted,[19] and perpendicular to its motion at *A*, it will then be drawn from the straight line *AF H*, and forced to revolve about *S* in the circle *A T W*; in the same manner, and by the same law, that a pebble is moved round in a sling. And if, when the body

Note 19. To make the projectile force a just balance to the gravitating power, so as to keep the planet moving in a circle, it must give such a velocity as the planet would acquire by gravity when it had fallen through half the semidiameter of that circle.

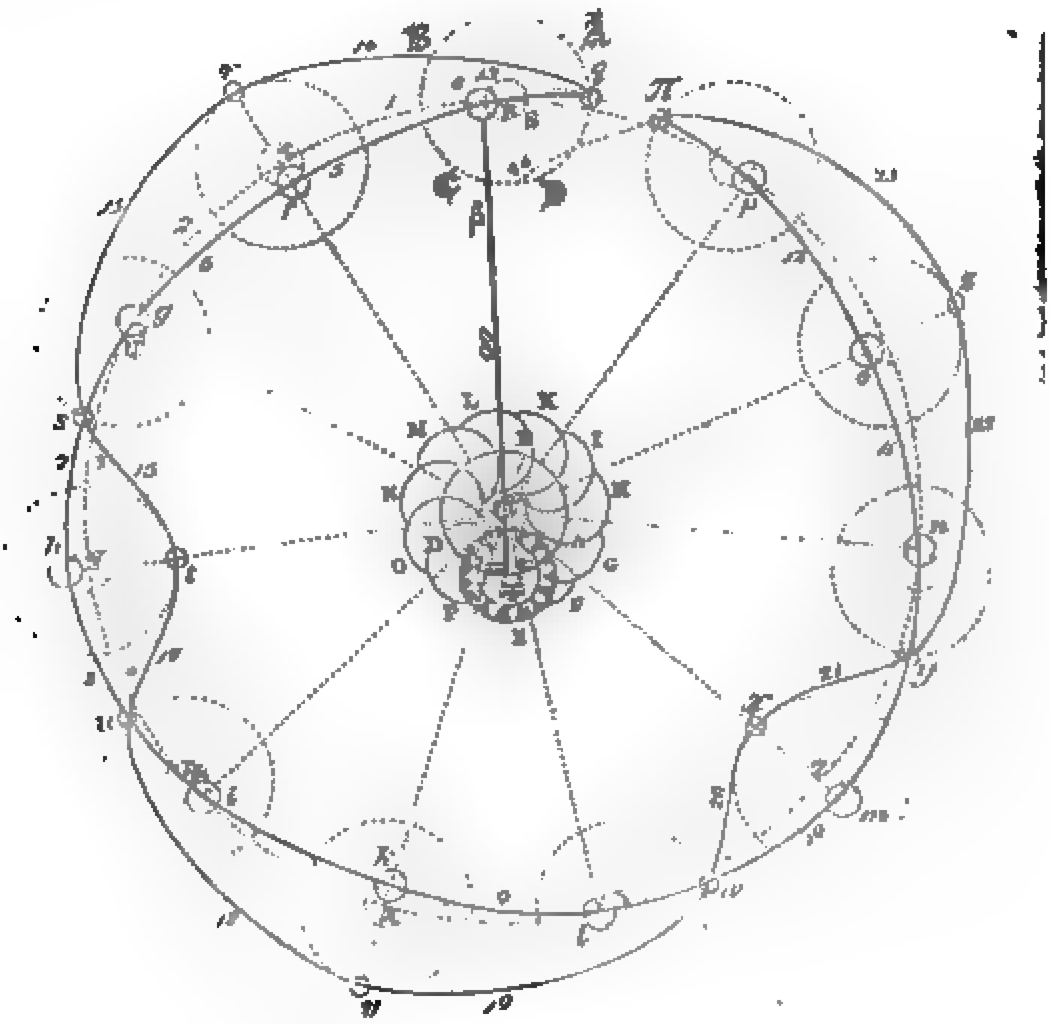
is in any part of its orbit (as suppose at *K*) a smaller body as *L*, within the sphere of attraction of the body *K*, be projected in the right line *L M*, with a force duly adjusted, and perpendicular to the line of attraction *LK*; then, the small body *L* will revolve about the large body *K* in the orbit *N O*, and accompany it in its whole course round the yet larger body *S*. But then, the body *K* will no longer move in the circle *A T W*; for that circle will now be described by the common center of gravity between *K* and *L*. Nay, even the great body *S* will not keep in the center; for it will be the common center of gravity between all the three bodies *S*, *K*, and *L*, that will remain immoveable there. So, if we suppose *S* and *K* connected by a wire *P* that has no weight, and *K* and *L* connected by a wire *q* that has no weight, the common center of gravity of all these three bodies will be a point in the wire *P* near *S*; which point being supported, the bodies will be all in *equilibrio* as they move round it. Though indeed, strictly speaking, the common center of gravity of all the three bodies will not be in the wire *P* but when these bodies are all in a right line. Here, *S* may represent the sun, *K* the earth, and *L* the moon.

LECT. II.

In order to form an idea of the curves described by two bodies revolving about their common center of gravity, whilst they themselves with a third body are in motion round the common center of gravity of all the three; let us first suppose *E* (p. 30.) to be the sun, and *e* the earth going round him without any moon; and their moving forces regulated as above. In this case, whilst the earth goes round the sun in the dotted circle *R T U W X*, &c. the sun will go round the circle *A B D*, whose center *C* is the common center of gravity between the sun and earth: the right line $\beta\delta$ representing the mutual attraction between them, by which they are as firmly connected as if they were fixed at the two

The curves described by bodies revolving about their common center of gravity.

LECT. II. ends of an iron bar strong enough to hold them. So, when the earth is at e, the sun will be at E; when the earth is at T, the sun will be at F: and when the earth is at g, the sun will be at G, &c.



Now, let us take in the moon q (at the top of the figure) and suppose the earth to have no progressive motion about the sun; in which case, whilst the moon revolves about in her orbit 𝔄 𝔅 ℭ 𝔇, the earth will revolve in the circle S 13, whose center R is the common center of gravity of the earth and moon; they being connected by the mutual attraction between them in the same manner as the earth and sun are.

But the truth is, that whilst the moon revolves about the earth, the earth is in motion about the sun: and now, the moon will cause the earth to describe an

irregular curve, and not a true circle, round the sun; it being the common center of gravity of the earth and moon that will then describe the same circle which the earth would have moved in, if it had not been attended by a moon. For, supposing the moon to describe a quarter of her progressive orbit about the earth in the time that the earth moves from *e* to *f*: it is plain, that when the earth comes to *f*, the moon will be found at *r*; in which time, their common center of gravity will have described the dotted arc *R* 1 *T*, the earth the curve *R* 5 *f*. and the moon the curve *q* 14 *r*. In the time that the moon describes another quarter of her orbit, the center of gravity of the earth and moon will describe the dotted arc *T* 2 *U*, the earth the curve *f* 6 *g*, the moon the curve *r* 15 *s*, and so on.—And thus, whilst the moon goes once round the earth in her progressive orbit, their common center of gravity describes the regular portion of a circle *R* 1 *T* 2 *U* 3 *V* 4 *W*, the earth the irregular curve *R* 5 *f* 6 *g* 7 *h* 8 *i*, and the moon the yet more irregular curve *q* 14 *r* 15 *s* 16 *t* 17 *u*; and then the same kind of tracks over again.

The center of gravity of the earth and moon is 6000 miles from the earth's center towards the moon; therefore the circle *S* 13 which the earth describes round that center of gravity (in every course of the moon round her orbit) is 12000 miles in diameter. Consequently the earth is 12000 miles nearer the sun at the time of full moon than at the time of new. [See the earth at *f* and at *h*.

To avoid confusion in so small a figure, we have supposed the moon to go only twice and a half round the earth, in the time that the earth goes once round the sun: it being impossible to take in all the revolutions which she makes in a year, and to give a true figure of her path, unless we should make the semidiameter of the earth's orbit at least 95 inches; and then, the pro-

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portional semidiameter of the moon's orbit would be only a quarter of an inch.—For a true figure of the moon's path, I refer the reader to my Treatise of Astronomy.

If the moon made any complete number of revolutions about the earth in the time that the earth makes one revolution about the sun, the paths of the sun and moon would return into themselves at the end of every year; and so be the same over again: but they return not into themselves in less than nineteen years nearly; in which time, the earth makes nearly nineteen revolutions about the sun, and the moon 235 about the earth.

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If the planet A [20] be attracted towards the sun, with such a force as would make it fall from A to B, in the time that the projectile impulse would have carried it from A to F, it will describe the arc $A\ G$ by the combined action of these forces, in the same time that the former would have caused it to fall from A to B, or the latter have carried it from A to F. But, if the projectile force had been twice as great, that is, such as would have carried the planet from A to H, in the same time that now, by the supposition, it carries it only from A to F; the sun's attraction must then have been four times as strong as formerly, to have kept the planet in the circle $A\ T\ W$; that is, it must have been such as would have caused the planet to fall from A to E, which is four times the distance of A from B, in the time that the projectile force singly would have carried it from A to H, which is only twice the distance of A from F.[21] Thus, a double projectile force will balance a quadruple power of gravity in the same circle; as appears plain by the figure, and shall soon be confirmed by an experiment.

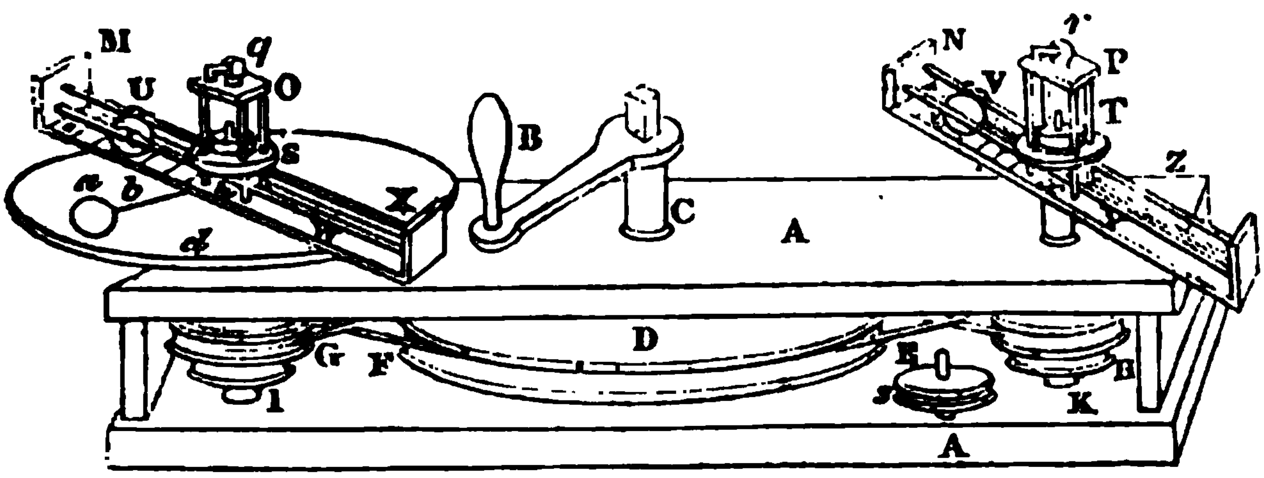
Note 20. See engraving at page 28.

Note 21. Here the arcs $A\ G$, $A\ I$ must be supposed to be very small; otherwise $A\ E$, which is equal to $H\ I$, will more than quadruple $A\ B$, which is equal to $F\ G$.

LECT. II.

The whirling-table described.

The whirling-table is a machine contrived for shewing experiments of this nature. *A A* is a strong frame



of wood, *B* a winch or handle fixed on the axis *C* of the wheel *D,* round which is the catgut string *F,* which also goes round the small wheels *G* and *K,* crossing between them and the great wheel *D.* On the upper end of the axis of the wheel *G,* above the frame, is fixed the round board *d,* to which the bearer *M S X* may be fastened occasionally, and removed when it is not wanted. On the axis of the wheel *H* is fixed the bearer *N T Z;* and it is easy to see that when the winch *B* is turned, the wheels and bearers are put into a whirling motion.

Each bearer has two wires, *W, X,* and *Y, Z,* fixed and screwed tight into them at the ends by nuts on the outside. And when these nuts are unscrewed, the wires may be drawn out in order to change the balls *U* and *V,* which slide upon the wires by means of brass loops, fixed into the balls, which keep the balls up from touching the wood below them. A strong silk line goes through each ball, and is fixed to it at any length from the center of the bearer to its end, as occasion requires, by a nut-screw at the top of the ball; the shank of the screw goes into the center of the ball, and presses the line against the under side of the hole that it goes through.—The line goes from the ball, and under a small pulley fixed in the middle of the bearer; then up through a socket in the round plate (see *S* and *T*) in

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the middle of each bearer; then through a slit in the middle of the square top (*O* and *P*) of each tower, and going over a small pulley on the top, comes down again the same way, and is at last fastened to the upper end of the socket fixed in the middle of the above mentioned round plate. These plates *S* and *T* have each four round holes near their edges, for letting them slide up and down upon the wires which make the corners of each tower. The balls and plates being thus connected, each by its particular line, it is plain that if the balls be drawn outward, or towards the ends *M* and *N* of their respective bearers, the round plates *S* and *T* will be drawn up to the top of their respective towers *O* and *P*.

There are several brass weights, some of two ounces, some of three, and some of four, to be occasionally put within the towers *O* and *P*, upon the round plates *S* and *T*: each weight having a round hole in the middle of it, for going upon the sockets or axes of the plates, and is slit from the edge to the hole, for allowing it to be slipped over the foresaid line which comes from each ball to its respective plate: thus

The experiments to be made by this machine are as follows:

The propensity of matter to keep the state it is in.

1. Take away the bearer *M X*,[22] and take the ivory ball *a*, to which the line or silk cord *b* is fastened at one end; and having made a loop on the other end of the cord, put the loop over a pin fixed in the center of the board *d*. Then, turning the winch *B* to give the board a whirling motion, you will see that the ball does not immediately begin to move with the board, but, on account of its inactivity, it endeavours to continue in the state of rest which it was in before.—Continue turning, until the board communicates an equal degree of motion with its own to the ball, and then turning on, you will perceive that the ball will remain upon one part of the

Note 22. See Engraving, page 33.

board, keeping the same velocity with it, and having no relative motion upon it, as is the case with every thing that lies loose upon the plane surface of the earth, which having the motion of the earth communicated to it, never endeavours to remove from that place. But stop the board suddenly by hand, and the ball will go on, and continue to revolve upon the board, until the friction thereof stops its motion: which shews, that matter being once put into motion, would continue to move for ever, if it met with no resistance. In like manner, if a person stands upright in a boat before it begins to move, he can stand firm; but the moment the boat sets off, he is in danger of falling towards that place which the boat departs from: because, as matter, he has no natural propensity to move. But when he acquires the motion of the boat, let it be ever so swift, if it be smooth and uniform, he will stand as upright and firm as if he was on the plane shore; and if the boat strikes against any obstacle, he will fall towards that obstacle; on account of the propensity he has, as matter, to keep the motion which the boat has put him into.

2. Take away this ball, and put a longer cord to it, which may be put down through the hollow axis of the bearer *MX*, and wheel *G*, and fix a weight to the end of the cord below the machine; which weight, if left at liberty, will draw the ball from the edge of the whirling-board to its center.

Bodies moving in orbits have a tendency to fly out of these orbits.

Draw off the ball a little from the center, and turn the winch; then the ball will go round and round with the board, and will gradually fly off farther and farther from the center, and raise up the weight below the machine: which shews that all bodies revolving in circles have a tendency to fly off from these circles, and must have some power acting upon them from the center of motion, to keep them from flying off.[23] Stop the machine, and

Note 23. There is a very beautiful as well as simple mode of illus-

LECT. II.

the ball will continue to revolve for some time upon the board; but as the friction gradually stops its motion, the weight acting upon it will bring it nearer and nearer to the center in every revolution, until it brings it quite thither. This shews, that if the planets met with any resistance in going round the sun, its attractive power would bring them nearer and nearer to it in every revolution, until they fell upon it.

Bodies move faster in small orbits than in large ones.

3. Take hold of the cord below the machine with one hand, and with the other throw the ball upon the round board as it were at right angles to the cord, by which means it will go round and round upon the board. Then observing with what velocity it moves, pull the cord below the machine, which will bring the ball nearer to the center of the board, and you will see the nearer the ball is drawn to the center, the faster it will revolve; as those planets which are nearest the sun revolve faster than those which are more remote; and not only go round sooner, because they describe smaller circles, but even move faster in every part of their respective circles.

Their centrifugal forces shewn.

4. Take away this ball, and apply the bearer *MX*, whose center of motion is in its middle at *w*, directly over the center of the whirling-board *d*. Then put two balls (*V* and *U*) of equal weights upon their bearing wires, and having fixed them at equal distances from their respective centers of motion *w* and *x* upon their silk cords, by the screw nuts, put equal weights in the towers *O* and *P*. Lastly, put the catgut strings *E* and *F* upon the grooves *G* and *H* of the small wheels, which being of equal diameters, will give equal velocities to the bearers above, when the winch *B* is turned: and

trating the centrifugal motion of a revolving body. It consists in filling a small pail with water, and it will be found, that the vessel may be made to revolve without any portion of the water being spilt. In all cases however, the velocity must be such, that the centrifugal force exceeds that of the gravitating force, otherwise the pail would discharge its contents when first inverted.

the balls U and V will fly off towards M and N; and will raise the weights in the towers at the same instant. This shews, that when bodies of equal quantities of matter revolve in equal circles with equal velocities, their centrifugal forces are equal. LECT. II.

5. Take away these equal balls, and instead of them, put a ball of six ounces into the bearer $M X$, at a sixth part of the distance $w z$ from the center, and put a ball of one ounce into the opposite bearer, at the whole distance $x y$, which is equal to $w z$ from the center of the bearer; and fix the balls at these distances on their cords, by the screw nuts at top; and then the ball U, which is six times as heavy as the ball V, will be at only a sixth part of the distance from its center of motion; and consequently will revolve in a circle of only a sixth part of the circumference of the circle in which V revolves. Now, let any equal weights be put into the towers, and the machine be turned by the winch; which (as the catgut string is on equal wheels below) will cause the balls to revolve in equal times; but V will move six times as fast as U, because it revolves in a circle of six times its radius; and both the weights in the towers will rise at once. This shews, that the centrifugal forces of revolving bodies (or their tendencies to fly off from the circles they describe) are in direct proportion to their quantities of matter multiplied into their respective velocities; or into their distances from the centers of their respective circles. For, supposing U, which weighs six ounces, to be two inches from its center of motion w, the weight multiplied by the distance is 12; and supposing V, which weighs only one ounce, to be 12 inches distant from the center of motion x, the weight 1 ounce multiplied by the distance 12 inches is 12. And as they revolve in equal times, their velocities are as their distances from the center, namely, as 1 to 6.

If these two balls be fixed at equal distances from their respective centers of motion, they will move with equal velocities; and if the tower O has 6 times as much weight put into it as the tower P has, the balls will raise their weights exactly at the same moment. This shews that the ball U, being six times as heavy as the ball V, has six times as much centrifugal force, in describing an equal circle with an equal velocity.

6. If bodies of equal weights revolve in equal circles with unequal velocities, their centrifugal forces are as the squares of the velocities. To prove this law by an experiment, let two balls U and V of equal weights be fixed on their cords at equal distances from their respective centers of motion w and x; and then let the string E be put round the wheel K (whose circ
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LECT. II.

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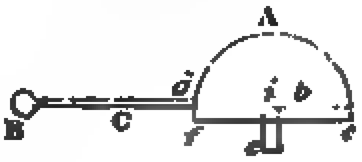
If one body moves round another, both of them must move round their common center of gravity.

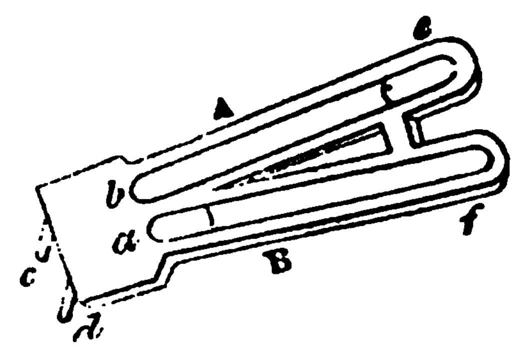


Note 25. See engraving, page 23.

LECT. II.

The absurdity of the Cartesian vortexes.

8. Take off the catgut string *E* from the great wheel *D* and the small wheel *H*, and let the string *F* remain upon the wheels *D* and *G*. Take away also the bearer *MX* from the whirling-board *d*, and instead thereof put the machine *AB* upon it, fixing this machine to the center of the board by the pins *c* and *d* in



such a manner, that the end *ef* may rise above the board to an angle of 30 or 40 degrees.[24] In the upper side of this machine are two glass tubes *a* and *b*, close stopped at both ends; and each tube is about three quarters full of water. In the tube *a* is a little quicksilver, which naturally falls down to the end *a* in the water, because it is heavier than its bulk of water; and on the tube *b* is a small cork which floats on the top of the water at *e*, because it is lighter; and it is small enough to have liberty to rise or fall in the tube. While the board *b*, with this machine upon it, continues at rest, the quicksilver lies at the bottom of the tube *a*, and the cork floats on the water near the top of the tube *b*. But, upon turning the winch, and putting the machine in motion, the contents of each tube will fly off towards the uppermost ends (which are farthest from the center of motion) the heaviest with the greatest force. Therefore the quicksilver in the tube *a* will fly off quite to the end *f*, and occupy its bulk of space there, excluding the water from that place, because it is lighter than quicksilver; but the water in the tube *b* flying off to its higher end *e*, will exclude the cork from that place, and cause the cork to descend towards the lowermost

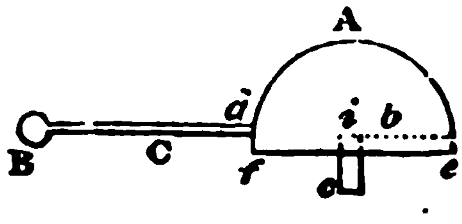
Note 24. A better mode of performing this experiment consists in screwing a hollow globe to the whirling table. If this be half filled with water, and a wax taper placed upon a cork float in the center, the water, on being whirled, will rise above its previous level, and occupy the equator of the globe, so that the taper will be seen to burn beneath the water, which will thus form a fluid wall around it several inches in height.

end of the tube, where it will remain upon the lowest end of the water near *b*; for the heavier body, having the greater centrifugal force, will therefore possess the uppermost part of the tube; and the lighter body will keep between the heavier and the lowermost part.

This demonstrates the absurdity of the Cartesian doctrine of the planets moving round the sun in vortexes; for, if the planet be more dense or heavy than its bulk of the vortex, it will fly off therein, farther and farther from the sun; if less dense, it will come down to the lowest part of the vortex, at the sun: and the whole vortex itself must be surrounded with something like a great wall, otherwise it would fly quite off, planets and all together.—But while gravity exists, there is no occasion for such vortexes; and when it ceases to exist, a stone thrown upwards will never return to the earth again.

If one body moves round another, both of them must move round their common center of gravity.

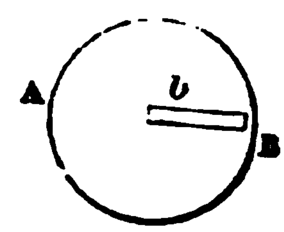
9. If a body be so placed on the whirling board of the machine,[*] that the center of gravity of the body be directly over the center of the board, and the board be put into ever so rapid a motion by the winch *B*, the body will turn round with the board, but will not remove from the middle of it; for, as all parts of the body are in *equilibrio* round its center of gravity, and the center of gravity is at rest in the center of motion, the centrifugal force of all parts of the body will be equal at equal distances from its center of motion, and therefore the body will remain in its place. But if the center of gravity be placed ever so little out of the center of motion, and the machine be turned swiftly round, the body will fly off towards that side of the board on which its center of gravity lies. Thus, if the wire *C* with its little ball *B* be taken away from the demi-globe *A*, and the flat side *e f* of this demi-globe be laid upon



[*] Note 25. See engraving, page 33.

LECT. II.

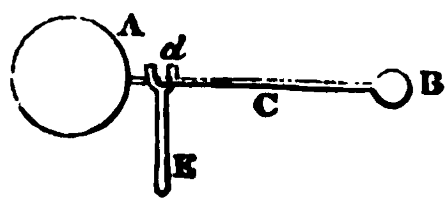
the whirling-board of the machine, so that their centers may coincide; if then the board be turned ever so quick by the winch, the demi-globe will remain where it was placed. But if the wire *C* be screwed into the demi-globe at *d*, thewhole becomes one body, whose center of gravity is now at or near *d*. Let the pin *c* be fixed in the center of the whirling-board, and the deep groove *b* cut in the flat side of the demi-globe be put upon the pin, so as the pin may be in the center of *A*, and let the whirling-board be turned by the winch, which will carry the little ball *B* [26] with its wire *C*, and the demi-globe *A*, all round the center-pin *c i;* and then, the centrifugal force of the little ball *B*, which weighs only one ounce, will be so great, as to draw off the demi-globe *A*, which weighs two pounds, until the end of the groove at *e* strikes against the pin *c*, and so prevents the demi-globe *A* from going any farther: otherwise, the centrifugal force of *B* would have been great enough to have carried *A* quite off the whirling-board. Which shews, that if the sun were placed in the very center of the orbits of the planets, it could not possibly remain there; for the centrifugal forces of the planets would carry them quite off, and the sun with them; especially when several of them happened to be in any one quarter of the heavens. For the sun and planets are as much connected by the mutual attraction that subsists between them, as the bodies *A* and *B* are by the wire *C* which is fixed into them both. And even if there were but one single planet in the whole heavens to go round ever so large a sun in the center of its orbit, its centrifugal force would soon carry off both itself and the sun. For, the greatest body placed in any part of free space might be easily moved: because, if there were no other body to attract it, it



Note 26. See Engraving, page 41.

could have no weight or gravity of itself; and consequently, though it could have no tendency of itself to remove from that part of space, yet it might be very easily moved by any other substance.

10. As the centrifugal force of the light body *B* will not allow the heavy body *A* to remain in the center of motion, even though it be twenty-four times as heavy as *B*; let us now take the ball *A*, which weighs six ounces, and connect it by the wire *C* with the ball *B*, which weighs only one ounce; and let the fork *E* be fixed into the center of the whirling-board: then hang the balls upon the fork by the wire *C* in such a manner, that they may exactly balance each other; which will be when the center of gravity between them, in the wire at *d*, is supported by the fork. And this center of gravity is as much nearer to the center of the ball *A*, than to the center of the ball *B*, as *A* is heavier than *B*, allowing for the weight of the wire on each side of the fork. This done, let the machine be put into motion by the winch; and the balls *A* and *B* will go round their common center of gravity *d*, keeping their balance, because either will not allow the other to fly off with it. For, supposing the ball *B* to be only one ounce in weight, and the ball *A* to be six ounces; then, if the wire *C* were equally heavy on each side of the fork, the center of gravity *d* would be six times as far from the center of the ball *B* as from that of the ball *A*, and consequently *B* will revolve with a velocity six times as great as *A* does; which will give *B* six times as much centrifugal force as any single ounce of *A* has: but then, as *B* is only one ounce, and *A* six ounces, the whole centrifugal force of *A* will exactly balance the whole centrifugal force of *B*: and therefore, each body will detain the other, so as to make it keep in its circle. This shews that the sun and planets must all move round the common *center of gravity* of the whole system, in



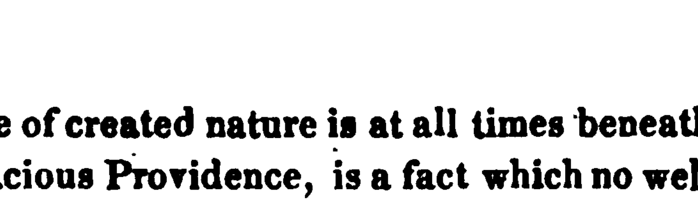
LECT. II. order to preserve that just balance which takes place among them. For, the planets being as inactive and dead as the above balls, they could no more have put themselves into motion than these balls can; nor have kept in their orbits without being balanced at first with the greatest degree of exactness upon their common center of gravity, by the Almighty hand that made them and put them in motion.

Perhaps it may be here asked, that since the center of gravity between these balls must be supported by the fork *E* in this experiment, *what* prop it is that supports the center of gravity of the solar system, and consequently bears the weight of all the bodies in it; and by what is the prop itself supported? The answer is easy and plain; for the center of gravity of our balls must be supported, because they gravitate towards the earth, and would therefore fall to it: but as the sun and planets gravitate only towards one another, they have nothing else to fall to; and therefore have no occasion for any thing to support their common center of gravity: and if they did not move round that center, and consequently acquire a tendency to fly off from it by their motions, their mutual attractions would soon bring them together; and so the whole would become one mass in the sun: which would also be the case if their velocities round the sun were not quick enough to create a centrifugal force equal to the sun's attraction.

But after all this nice adjustment, it appears evident that the Deity cannot withdraw his regulating hand from his works, and leave them to be solely governed by the laws which he has impressed upon them at first. For if he should once leave them so, their order would in time come to an end; because the planets must necessarily disturb one another's motions by their mutual attractions, when several of them are in the same quarter of the heavens; as is often the case: and then, as they

attract the sun more towards that quarter than when they are in a manner dispersed equably around him, if he was not at that time made to describe a portion of a larger circle round the common center of gravity, the balance would then be immediately destroyed; and as it could never restore itself again, the whole system would begin to fall together, and would in time unite in a mass at the sun.[27]—Of this disturbance we have a very remarkable instance in the comet which appeared lately; and which, in going last up before from the sun, went so near to Jupiter, and was so affected by his attraction, as to have the figure of its orbit much changed; and not only so, but to have its period altered, and its course to be different in the heavens from what it was last before.

11. Take away the fork and balls from the whirling-board, and place the trough *A B* thereon, fixing its center to the center of the whirling-board by the pin *H*. In this trough are two balls *D* and *E*, of unequal weights, connected by a wire *f*; and made to slide easily upon the



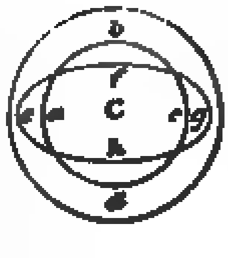
Note 27. That every particle of created nature is at all times beneath the controul of a good and gracious Providence, is a fact which no well regulated mind, will, for an instant, attempt to controvert. But it is also a fact, that the more we examine the handy works of the Divine Architect of the Universe, the more reason have we to exclaim with the Psalmist, "How good and great, O Lord, are all thy works, in wisdom thou hast formed them all!"

Illustrations of this truth must continually offer themselves to the attentive observer of Nature's laboratory; and, in no case is this more obvious, than in the various compensatory motions of the planetary bodies, by which every apparent inequality that has been found to occur in their relative situations is found to be balanced by derangements of an equal, though opposite kind.

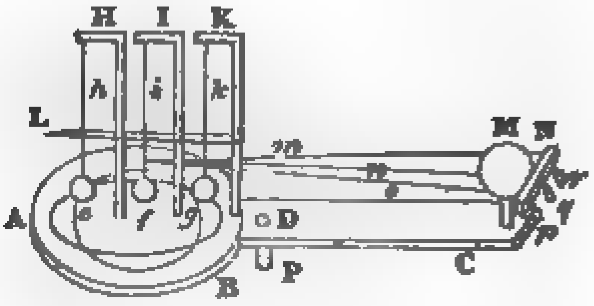
LECT. II. wire *C* stretched from end to end of the trough, and made fast by nut-screws on the outside of the ends. Let these balls be so placed upon the wire *C*, that their common center of gravity *g* may be directly over the center of the whirling-board. Then, turn the machine by the winch, ever so swiftly, and the trough and balls will go round their center of gravity, so as neither of the balls will fly off; because, on account of the equilibrium, each ball detains the other with an equal force acting against it. But if the ball *E* be drawn a little more towards the end of the trough at *A*, it will remove the center of gravity towards that end from the center of motion; and then, upon turning the machine, the little ball *E* will fly off, and strike with a considerable force against the end *A*, and draw the great ball *B* into the middle of the trough. Or, if the great ball *D* be drawn towards the end *B* of the trough, so that the center of gravity may be a little towards that end from the center of motion, and the machine be turned by the winch, the great ball *D* will fly off, and strike violently against the end *B* of the trough, and will bring the little ball *E* into the middle of it. If the trough be not made very strong, the ball *D* will break through it.

Of the tides. 12. The reason why the tides rise at the same absolute time on opposite sides of the earth, and consequently in opposite directions, is made abundantly plain by a new experiment on the whirling-table. The cause of their rising on the side next the moon every one understands to be owing to the moon's attraction: but why they should rise on the opposite side at the same time, where there is no moon to attract them, is perhaps not so generally understood. For it would seem, that the moon should rather draw the waters (as it were) closer to that side, than raise them upon it, directly contrary to her attractive force. Let the circle *a b c d*

represent the earth, with its side *c* turned towards the moon, which will then attract the waters so, as to raise them from *c* to *g*. But the question is, why should they rise as high at that very time on the opposite side, from *a* to *e*? In order to explain this, let there be a plate *A B* fixed upon



one end of the flat bar *D C*; with such a circle drawn upon it as *a b c d* (in the preceding figure) to represent the round figure of the earth

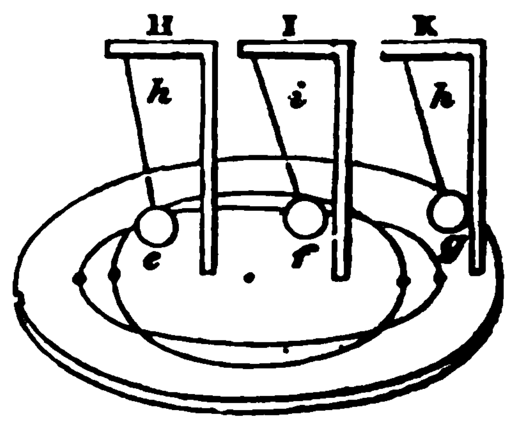


and sea; and such an ellipsis as *e f g h* to represent the swelling of the tide at *e* and *g*, ocasioned by the influence of the moon. Over this plate *A B*, let the three ivory balls *e f g*, be hung by the silk lines *h i k*, fastened to the tops of the crooked wires *H I K*, in such a manner, that the ball at *e* may hang freely over the side of the circle *e*, which is farthest from the moon *M* (at the other end of the bar ;) the ball at *f* may hang freely over the center, and the ball at *g* hang over the side of the circle *g*, which is nearest the moon. The ball *f* may represent the center of the earth, the ball *g* some water on the side next the moon, and the ball *e* some water on the opposite side. On the back of the moon *M* is fixed the short bar *N* parallel to the horizon, and there are three holes in it above the little weights *p, q, r*. A silk thread *o* is tied to the line *k* close above the ball *g*, and passing by one side of the moon *M*, goes through a hole in the bar *N*, and has the weight *p* hung to it. Such another thread *n* is tied to the line *i*, close above the ball *f*, and passing through the center of the moor. *M* and middle of the bar *N*, has the weight *q* hung to it, which is lighter than the weight

LECT. II.

p. A third thread *m* is tied to the line *h*, close above the ball *e*, and passing by the other side of the moon *M*, through the bar *N*, has the weight *r* hung to it, which is lighter than the weight *q*.

The use of these three unequal weights is to represent the moon's unequal attraction at different distances from her. With whatever force she attracts the center of the earth, she attracts the side next her with a greater degree of force, and the side farthest from her with a less. So, if the weights are left at liberty, they will draw all the three balls towards the moon with different degrees of force, and cause them to make this appearance; by which means they are evidently farther from each other than they would be if they hung at liberty by the lines *h, i, k;* because the lines would then hang perpendicularly. This shews that as the moon attracts the side of the earth which is nearest her with a greater degree of force than she does the center of the earth, she will draw the water on that side more than she draws the center, and so cause it to rise on that side; and as she draws the center more than she draws the opposite side, the center will recede farther from the surface of the water on that opposite side, and so leave it as high there as she raised it on the side next to her. For, as the center will be in the middle between the tops of the opposite elevations, they must of course be equally high on both sides at the same time.[28]



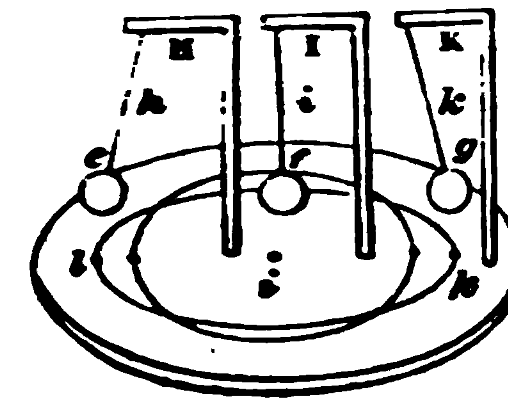
Note 28. The united operations of the sun and moon in producing the phænomena of the tides are more amply, as well as more accurately, described in our author's Treatise on Astronomy, of which a new edition is now ready for the press.

LECT. II.

But upon this supposition the earth and moon would soon come together: and to be sure they would, if they had not a motion round their common center of gravity, to create a degree of centrifugal force sufficient to balance their mutual attraction. This motion they have; for as the moon goes round her orbit every month, at the distance of 240,000 miles from the earth's center, and of 234,000 miles from the center of gravity of the earth and moon, so does the earth go round the same center of gravity every month at the distance of 6000 miles from it; that is, from it to the center of the earth. Now as the earth is (in round numbers) 8000 miles in diameter, it is plain that its side next the moon is only 2000 miles from the common center of gravity of the earth and moon; its center 6000 miles distance therefrom; and its farther side from the moon 10,000. Therefore the centrifugal forces of these parts are as 2000, 6000, and 10,000; that is, the centrifugal force of any side of the earth, when it is turned from the moon, is five times as great as when it is turned towards the moon. And as the moon's attraction (expressed by the number 6000) at the earth's center keeps the earth from flying out of this monthly circle, it must be greater than the centrifugal force of the waters on the side next her; and consequently, her greater degree of attraction on that side is sufficient to raise them; but as her attraction on the opposite side is less than the centrifugal force of the water there, the excess of this force is sufficient to raise the water just as high on the opposite side.—To prove this experimentally, let the bar *D C* (in page 47) with its furniture be fixed upon the whirling board of the machine (page 33) by pushing the pin *P* into the center of the board; which pin is in the center of gravity of the whole bar with its three balls *e*, *f*, *g*, and moon *M*. Now if the whirling-board and bar be turned slowly round by the winch, until the ball

LECT. II.

f hangs over the center of the circle, as the ball *g* will be kept towards the moon by the heaviest weight *p*, (see page 47.) and the ball *e*, on account of its greater centrifugal force, and the lesser weight *r*, will fly off as far to the other side, (as in this engraving.)



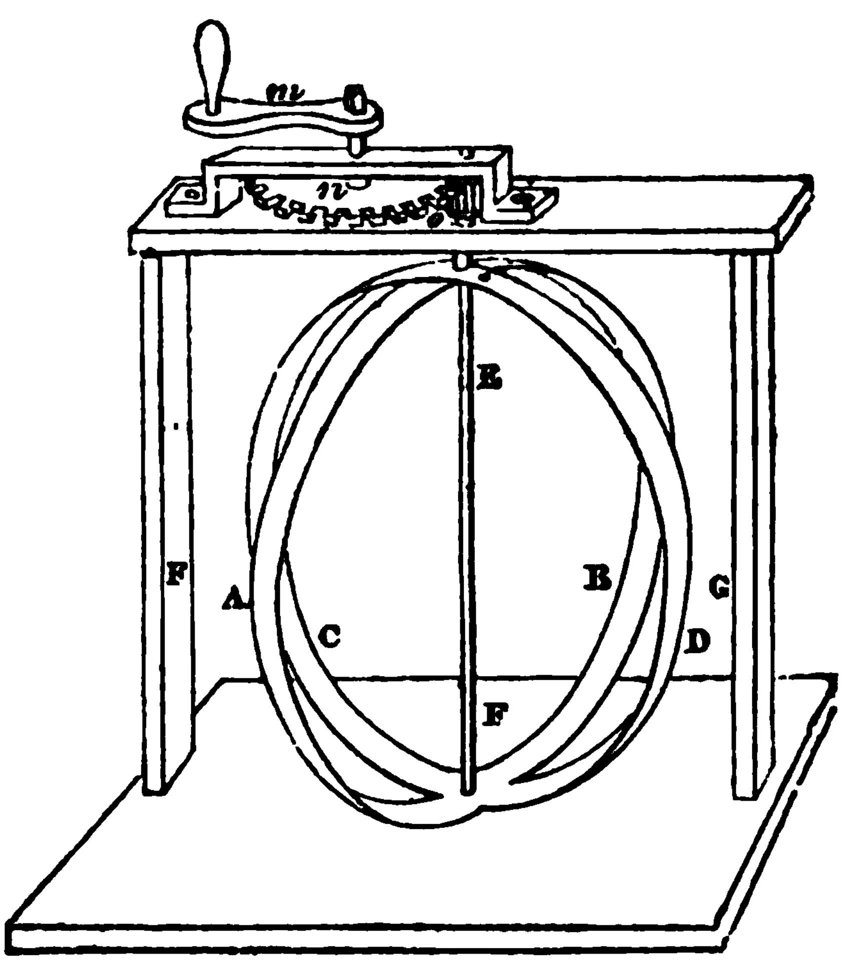
And so, whilst the machine is kept turning, th balls *e* and *g* will hang over the ends of the ellipse *l f k*. So that the centrifugal force of the ball *e* will ex ceed the moon's attraction just as much as her attrac tion exceeds the centrifugal force of the ball *g*, whil her attraction just balances the centrifugal force of th ball *f*, and makes it keep in its circle. And hence is evident, that the tides must rise to equal heights the same time on opposite sides of the earth. Th experiment, to the best of my knowledge, is entire new.

The earth's motion demonstrated.

From the principles thus established, it is evident th the earth moves round the sun, and not the sun roun the earth: for the centrifugal law will never allow great body to move round a small one in any orbit wha ever; especially when we find that if a small body mov round a great one, the great one must also move roun the common center of gravity between the two. A it is well known that the quantity of matter in the s is 227,000 times as great as the quantity of matter in t earth. Now, as the sun's distance from the earth is least 81,000,000 of miles, if we divide that distance 227,000, we shall have only 357 for the number of mi that the center of gravity between the sun and earth distant from the sun's center. And as the sun's sem diameter is ¼ of a degree, which, at so great a distan as that of the sun, must be no less than 381,500 mil if this be divided by 357, the quotient will be 10

which shews that the common center of gravity between the sun and earth is within the body of the sun; and is only the 10681 part of his semidiameter from his center towards his surface. LECT. II.

All globular bodies, whose parts can yield, and which do not turn on their axes, must be perfect spheres, because all parts of their surfaces are equally attracted toward their centers. But all such globes as do not turn on their axes will be oblate spheroids; that is, their surfaces will be higher, or farther from the center, in the equatorial than in the polar regions. For, as the equatorial parts must be quickest, they must have the greatest centrifugal force; and will therefore recede farthest from the axis of motion. Thus, if two circular hoops *A B* and *C D*, made thin and flexible, & crossing one another at right angles, be turned round their axis *E F* by means of the winch *m*, the wheel *n*, and pinion *o*, and the axis be loose in the pole or intersection *e*, the middle parts *A*, *B*, *C*, *D* will swell out so as to strike against the sides of the frame at *F* and *G*, if the pole *e*, in sinking to the pin *E*, be not stopped by it from sinking farther: so that the whole will appear of an oval figure, the equatorial diameter being considerably longer than the polar. That our earth is of this



LECT. II. figure, is demonstrable from actual measurement of some degrees on its surface, which are found to be longer in the frigid zones than in the torrid: and the difference is found to be such as proves the earth's equatorial diameter to be thirty-six miles longer than its axis.[29]—Seeing then, the earth is higher at the equator than at the poles, the sea, which like all other fluids naturally runs downward (or towards the places which are nearest the earth's center), would run towards the polar regions, and leave the equatorial parts dry, if the centrifugal force of the water, which carried it to those parts, and so raised them, did not detain and keep it from running back again towards the poles of the earth.[30]

Note. 29. Subsequent observations have shewn that the difference between the polar and equatorial diameters of the earth is as 7934.9 to 7908.5 or rather more than twenty-six miles. While the planet Saturn, whose velocity is much greater than that of the earth is as 11 to 10.

Note 30. As every particle of matter is subject to the same laws, it will be evident that the atmosphere which surrounds our globe must take a similar form. This curious fact has been experimentally illustrated by Dr. Birkbeck in a Lecture delivered in the Theatre of the London Institution, and a series of barometrical observations have shewn that there is an aerial tide nearly as well defined as that of the ocean.

LECTURE III.

OF THE MECHANICAL POWERS.

IF we consider bodies in motion, and compare them together, we may do this either with respect to the quantities of matter they contain, or the velocities with which they are moved. The heavier any body is, the greater is the power required either to move it or to stop its motion: and again, the swifter it moves, the greater is its force. So that the whole *momentum*, or quantity of force of a moving body, is the result of its quantity of matter multiplied by the velocity with which it is moved. And when the products arising from the multiplication of the particular quantities of matter in any two bodies by their respective velocities are equal, the *momenta* or entire forces are so too. Thus, suppose a body, which we shall call *A*, to weigh forty pounds, and to move at the rate of two miles in a minute; and another body, which we shall call *B*, to weigh only four pounds, and to move twenty miles in a minute; the entire forces with which these two bodies would strike against any obstacle would be equal to each other, and therefore it would require equal powers to stop them. For forty multiplied by two gives eighty, the force of the body *A*; and twenty multiplied by four gives eighty, the force of the body *B*.

The foundation of all mechanics.

Upon this easy principle depends the whole of mechanics: and it holds universally true, that when two bodies are suspended on any machine, so as to act contrary to each other; if the machine be put into motion, and the perpendicular ascent of one body multiplied into its weight, be equal to the perpendicular descent of the other body multiplied into its weight, these

LECT. III. bodies, how unequal soever in their weights, will balance one another in all situations: for, as the whole ascent of one is performed in the same time with the whole descent of the other, their respective velocities must be directly as the spaces they move through; and the excess of weight in one body is compensated by the excess of velocity in the other.—Upon this principle it is easy to compute the power of any mechanical engine, whether simple or compound; for it is but only finding how much swifter the power moves than the weight does (i. e. how much farther in the same time), and just so much is the power increased by the help of the engine.

How to compute the power of any mechanical engine.

In the theory of this science, we suppose all planes perfectly even, all bodies perfectly smooth, levers to have no weight, cords to be extremely pliable, machines to have no friction; and in short, all imperfections must be set aside until the theory be established; and then, proper allowances are to be made.

The mechanical powers, what.

The simple *machines*, usually called *mechanical powers*, are six in number, viz. the *lever*, the *wheel and axle*, the *pulley*, the *inclined plane*, the *wedge*, and the *screws*.[a]—They are called mechanical powers, because they help us mechanically to raise weights, move heavy bodies, and overcome resistances, which we could not effect without them.

The *lever*.

1. A *lever* is a bar of iron or wood, one part of which being supported by a prop, all the other parts turn upon that prop as their center of motion: and the velocity of every part or point is directly as its distance from the prop. Therefore, when the weight to be raised at one end is applied to the power at the other to raise it,

Note 31. It is generally admitted that the six mechanical powers enumerated by our author may fairly be reduced to two, as the pulley and the wheel may be referred to the lever; whilst the wedge and the screw are but modifications of the inclined plane.

as the distance of the power from the prop is to the distance of the weight from the prop, the power and weight will exactly balance or counterpoise each other: and as a common lever has next to no friction on its prop, a very little additional power will be sufficient to raise the weight.

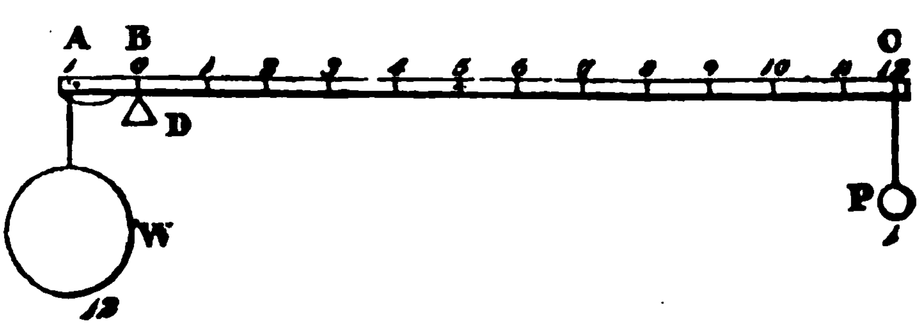
There are four kinds of levers. 1. The common sort, where the prop is placed between the weight and the power; but much nearer to the weight than to the power. 2. When the prop is at one end of the lever, the power at the other, and the weight between them. 3. When the prop is at one end, the weight at the other, and the power applied between them. 4. The bended lever, which differs only in form from the first sort, but not in property. Those of the first and second kind are often used in mechanical engines; but there are few instances in which the third sort is used.

The balance.

A *common balance* is by some reckoned a lever of the first kind; but as both its ends are at equal distances from its center of motion, they move with equal velocities; and therefore, as it gives no mechanical advantage, it cannot properly be reckoned among the mechanical powers. [32]

The first kind of lever.

A lever of the first kind is represented by the bar *A B C*, supported by the



Note 32. The opposite arms of a balance are sometimes made unequal for fraudulent purposes, the axis being placed nearer the substance to be weighed, than to the weight, which will thus obtain a decided mechanical advantage. In that case, however, the fraud may be readily detected by changing the contents of the two scales; so that the mechanical advantage which was in the first instance given to the scale intended to contain the goods about to be weighed, will be transferred to the opposite end of the lever, and the disproportion will then become apparent.

LECT. III. prop *D*. Its principal use is to loosen large stones in the ground, or raise great weights to small heights, in order to have ropes to put under them for raising them higher by other machines. The parts *A B* and *B C*, on different sides of the prop *D*, are called the *arms* of the lever: the end *A* of the shorter arm *AB* being applied to the weight intended to be raised, or to the resistance to be overcome; and the power applied to the end *C* of the longer arm *BC*.

In making experiments with this machine, the shorter arm *AB* must be as much thicker than the longer arm *BC*, as will be sufficient to balance it on the prop. This supposed, let *P* represent a power, whose gravity is equal to 1 ounce, and *W* a weight, whose gravity is equal to 12 ounces. Then, if the power be twelve times as far from the prop as the weight is, they will exactly counterpoise; and a small addition to the power *P* will cause it to descend, and raise the weight *W*; and the velocity with which the power descends will be to the velocity with which the weight rises, as 12 to 1: that is, directly as their distances from the prop; and consequently, as the spaces through which they move. Hence, it is plain that a man, who by his natural strength, without the help of any machine, could support a hundred weight, will, by the help of this lever, be enabled to support twelve hundred. If the weight be less, or the power greater, the prop may be placed so much farther from the weight; and then it can be raised to a proportionably greater height. For, universally, if the intensity of the weight multiplied into its distance from the prop be equal to the intensity of the power multiplied into its distance from the prop, the power and weight will exactly balance each other; and a little addition to the power will raise the weight. Thus, in the present instance, the weight *W* is 12 ounces, and its distance from the prop is 1 inch; and 12 multiplied by 1 is 12; the power *P* is equal to 1 ounce, and its distance from the prop is 12 inches, which multiplied by 1 is 12

again; and therefore there is an equilibrium between them. So, if a power equal to 2 ounces be applied at the distance of 6 inches from the prop, it will just balance the weight *W;* for 6 multiplied by 2 is 12, as before. And a power equal to 3 ounces placed at 4 inches distance from the prop would be the same; for 3 times 4 is 12; and so on, in proportion. LECT. III.

The *statera* or Roman *steelyard* is a lever of this kind, and is used for finding the weights of different bodies by one single weight placed at different distances from the prop or center of motion *D*. For, if a scale hangs at *A*, the extremity of the shorter arm *AB*, and is of such a weight as will exactly counterpoise the longer arm *B C;* if this arm be divided into as many equal parts as it will contain, each equal to *AB*, the single weight *P* (which we may suppose to be 1 pound) will serve for weighing any thing as heavy as itself, or as many times heavier as there are divisions in the arm *BC*, or any quantity between its own weight and that quantity. As for example, if *P* be 1 pound, and placed at the first division 1 in the arm *BC*, it will balance 1 pound in the scale at *A*: if it be removed to the second division at 2, it will balance 2 pounds in the scale: if to the third, 3 pounds; and so on to the end of the arm *BC*. If each of these integral divisions be subdivided into as many equal parts as a pound contains ounces, and the weight *P* be placed at any of these subdivisions, so as to counterpoise what is in the scale, the pounds and odd ounces therein are by that means ascertained. The *steel-yard.*

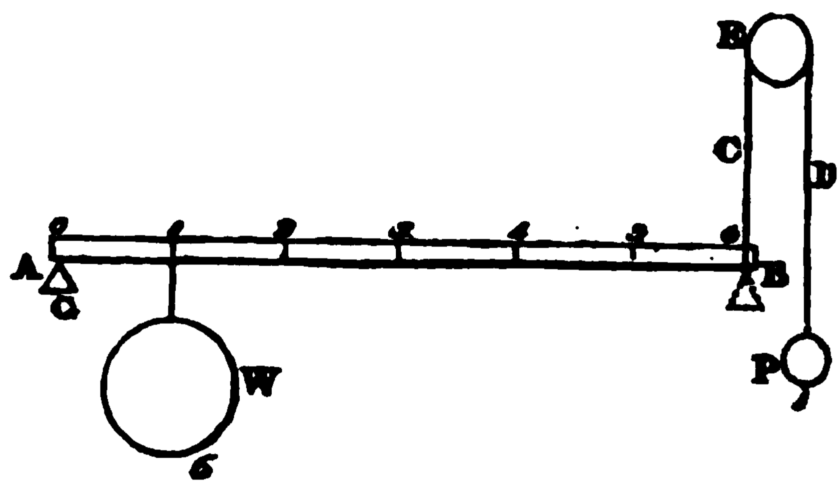
To this kind of lever may be reduced several sorts of instruments, such as scissars, pincers, snuffers; which are made of two levers acting contrary to one another: their prop or center of motion being the pin which keeps them together.

In common practice, the longer arm of this lever greatly exceeds the weight of the shorter; which gains great advantage, because it adds so much to the power

LECT. III.

The second kind of lever.

A lever of the second kind has the weight between the prop and the power. In this, as well as the former, the advantage gained is as the distance of the power from the prop to the distance of the weight from the prop: for the respective velocities of the power and weight are in that proportion; and they will balance each other when the intensity of the power multiplied by its distance from the prop is equal to the intensity of the weight multiplied by its distance from the prop. Thus, if *AB* be a lever on which the weight *W* of 6 ounces hangs at the distance of one inch from the prop *G*, and a power *P* equal to the weight of one



ounce hangs at the end *B*, 6 inches from the prop, by the cord *CD* going over the fixed pulley *E*, the power will just support the weight; and a small addition to the power will raise the weight 1 inch for every 6 inches that the power descends.

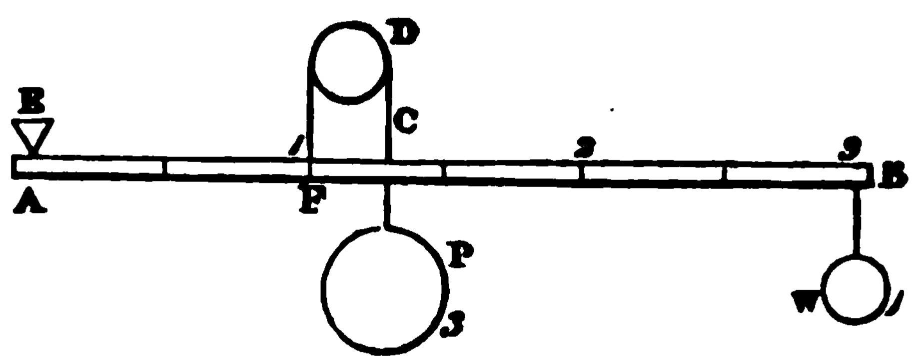
This lever shews the reason why two men carrying a burden upon a stick between them, bear unequal shares of the burden in the inverse proportion of their distances from it. For it is well known, that the nearer any of them is to the burden, the greater share he bears of it: and if he goes directly under it, he bears the whole. So, if one man be at *G*, and the other at *P*, having the pole or stick *AB* resting on their shoulders; if the burden or weight *W* be placed five times as near the man at *G*, as it is to the man at *P*, the former will bear five times as much weight as the latter. This is likewise applicable to the case of two horses of unequal strength, to be so yoked, as that each horse may draw a part proportionable to his strength; which is done by so dividing the beam they pull, that the point of

traction may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter. LECT I.

To this kind of lever may be reduced oars, rudders of ships, doors turning upon hinges, cutting knives, which are fixed at the point of the blade, and the like,

The third lever.

If in this lever we suppose the power and weight to change places, so that the power may be between the weight and the prop, it will become a lever of the third kind: in which, that there may be a balance between the power and the weight, the intensity of the power must exceed the intensity of the weight, just as much as the distance of the weight from the prop exceeds the distance of the power from it. Thus, let *E* be the prop of the lever *AB* and *W* a weight of one pound, placed 3 times as far from the prop as the power *P* acts at *F*, by the cord *C* going over the fixed pulley *D*; in this case, the power must be equal to three pounds, in order to support the weight.



To this sort of lever are generally referred the bones of a man's arm: for when we lift a weight by the hand, the muscle that exerts its force to raise that weight, is fixed to the bone about one tenth part as far below the elbow as the hand is. And the elbow being the center round which the lower part of the arm turns, the muscle must therefore exert a force ten times as great as the weight that is raised.[33]

As this kind of lever is a disadvantage to the moving

Note 33. The actual loss of power is greater than what our Author has stated, and yet this apparent disadvantage is abundantly compensated for by the greater compactness and usefulness of the limb

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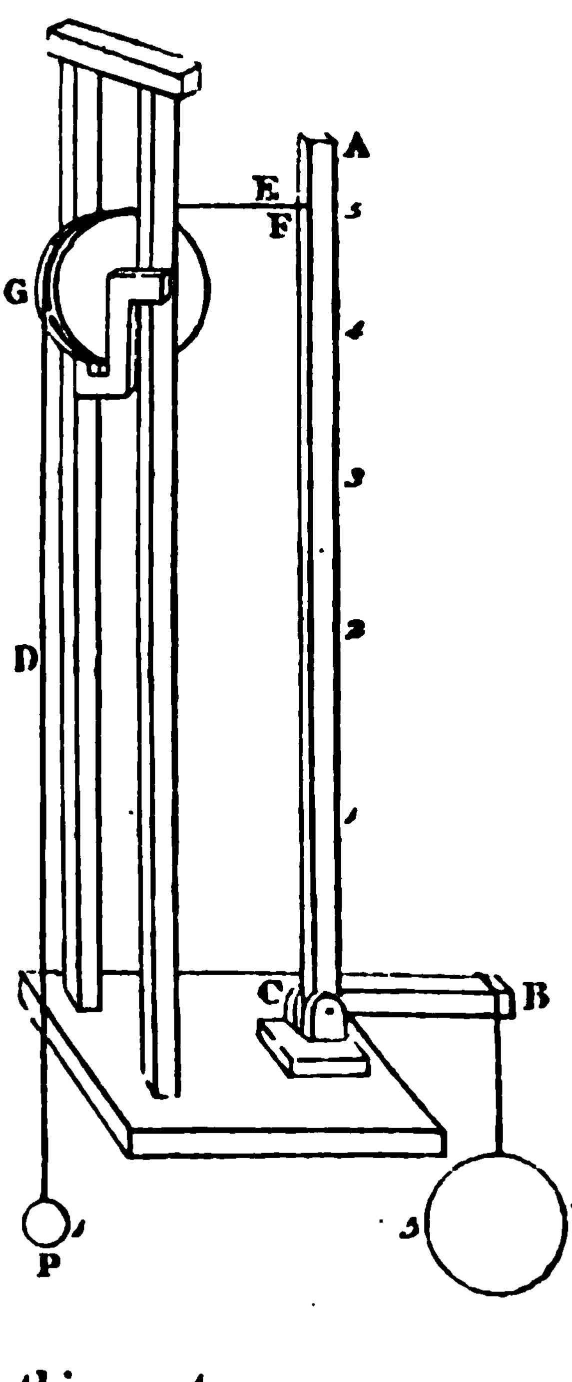
power, it is never used but in cases of necessity; such as that of a ladder, which being fixed at one end, is by the strength of a man's arms reared against a wall. And in clock-work, where all the wheels may be reckoned levers of this kind, because the power that moves every wheel, except the first, acts upon it near the center of motion by means of a small pinion, and the resistance it has to overcome, acts against the teeth round its circumference.

The fourth kind of lever.

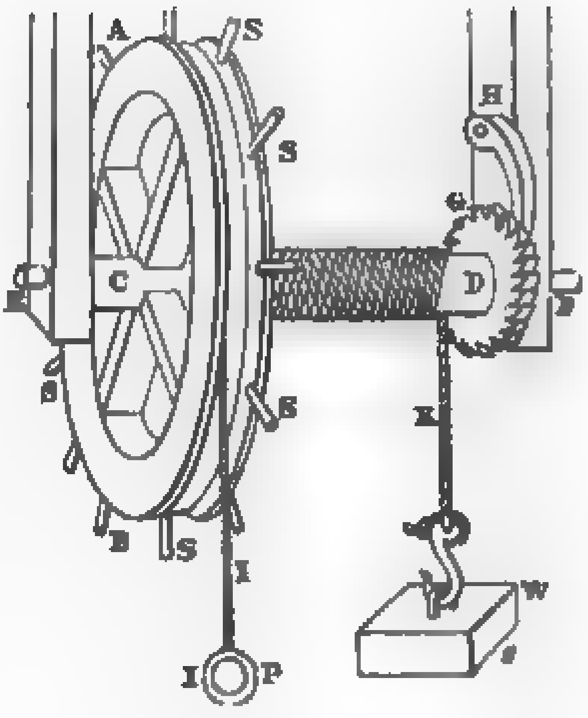
The fourth kind of lever differs nothing from the first, but in being bended for the sake of convenience. *A C B* is a lever of this sort, bended at *C*, which is its prop, or center of motion. *P* is a power acting upon the longer arm *A C* at *F*, by means of the cord *D E* going over the pulley *G*; and *W* is a weight or resistance acting upon the end *B* of the shorter arm *B C*. If the power be to the weight, as *C B* is to *C F*, they are in *equilibrio*. Thus, suppose *W* to be five pounds acting at the distance of one foot from the center of motion *C*, and *P* to be one pound acting at *F*, five feet from the center *C*, the power and weight will just balance each other. A hammer drawing a nail is a lever of this sort.



The *wheel and axle*.

2. The second mechanical power is the *wheel and axle*, in which the power is applied to the circumference of the wheel, and the weight is raised by a rope which coils

t the axle as the wheel is turned round. Here it is that the velocity of the power must be to the ve-; of the weight, as the circumference of the wheel the circumference of the axle: and consequently, ower and weight will balance each other, when the sity of the power is to the intensity of the weight, e circumference of the axle is to the circumference he wheel. Let be a wheel, *C D* xle, and suppose circumference of wheel to be eight s as great as the umference of the ; then, a power qual to one pound, ging by the cord which goes round wheel, will bal-e a weight *W* of it pounds, hanging the rope *K*, which



s round the axle. And as the friction on the pivots or lgeons of the axle is but small, a small addition to the ver will cause it to descend, and raise the weight: but weight will rise with only an eighth part of the velo- wherewith the power descends, and consequently, ough no more than an eighth part of an equal space, the same time. If the wheel be pulled round by the ndles *S, S*, the power will be increased in proportion their length. And by this means, any weight may be sed as high as the operator pleases.

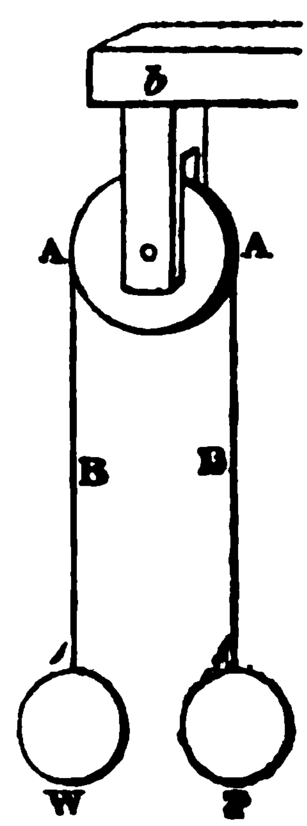
To this sort of engine belong all cranes for raising eat weights; and in this case, the wheel may have s all round it instead of handles, and a small lantern trundle may be made to work in the cogs, and be

LECT. III. turned by a winch; which will make the power of the engine to exceed the power of the man who works it, as much as the number of revolutions of the winch exceed those of the axle *D*, when multiplied by the excess of the length of the winch above the length of the semidiameter of the axle, added to the semidiameter or half thickness of the rope *K*, by which the weight is drawn up.—Thus, suppose the diameter of the rope and axle taken together, to be 13 inches, and consequently, half their diameters to be 6½ inches; so that the weight *W* will hang at 6½ inches perpendicular distance from below the center of the axle. Now, let us suppose the wheel *A B*, which is fixed on the axle, to have 80 cogs, and to be turned by means of a winch six inches long, fixed on the axis of a trundle of eight staves or rounds, working in the cogs of the wheel.—Here it is plain, that the winch and trundle would make 10 revolutions for one of the wheel *A B*, and its axis *D*, on which the rope *K* winds in raising the weight *W*; and the winch being no longer than the sum of the semidiameters of the great axle and rope, the trundle could have no more power on the wheel, than a man could have by pulling it round by the edge, because the winch would have no greater velocity than the edge of the wheel has, which we here suppose to be ten times as great as the velocity of the rising weight: so that, in this case, the power gained would be as 10 to 1. But if the length of the winch be 12 inches, the power gained will be as 20 to 1: if 18 inches (which is long enough for any man to work by) the power gained would be as 30 to 1; that is, a man could raise 30 times as much by such an engine, as he could do by his natural strength without it, because the velocity of the handle of the winch would be 30 times as great as the velocity of the rising weight; the absolute force of any engine being in proportion to the velocity of the power to the velocity of the weight raised by it.—

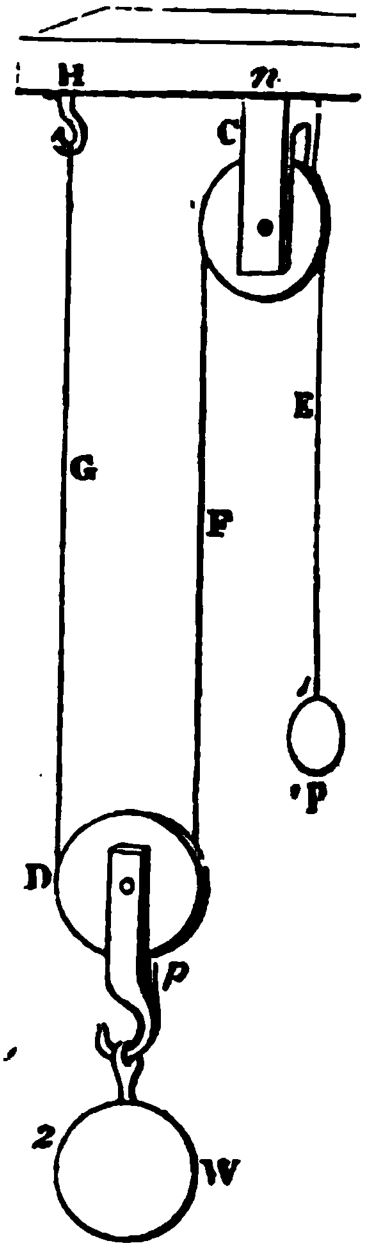
ıen, just as much power or advantage as is gained LECT. III.
: engine, so much time is lost in working it. In
ort of machines it is requisite to have a ratchet-
G on one end of the axle, with a catch *H* to fall
ts teeth; which will at any time support the
t, and keep it from descending, if the workman
l, through inadvertency or carelessness, quit his
vhilst the weight is raising. And by this means,
anger is prevented which might otherwise hap-
y the running down of the weight when left at
r.

The pulley.

Ihe third mechanical power or engine consists of one *moveable pulley*, or a *system of pulleys*; some lock or case which is fixed, and others in a block is moveable, and rises with the weight. For h a single pulley that only turns ı axis, and moves not out of ace, may serve to change the di-n of the power, yet it can give no ınical advantage thereto; but is ıs the beam of a balance, whose are of equal length and weight. if the equal weights *W* and *P* hang cord *B B* upon the pulley *A*, whose *b* is fixed to a beam, they :ounterpoise each other, just in the manner as if the cord were cut in iddle, and its two ends hung upon ooks fixed in the pulley at *A* and ıually distant from its center.



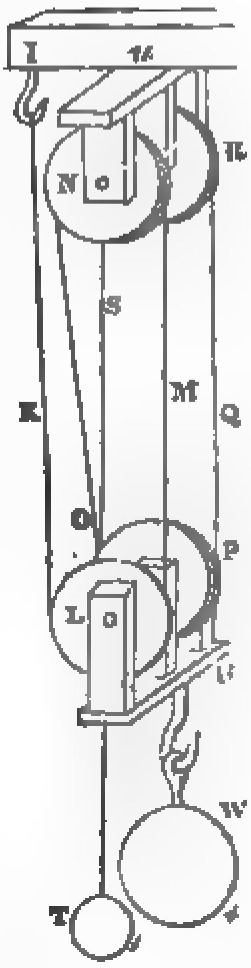
LECT. III.

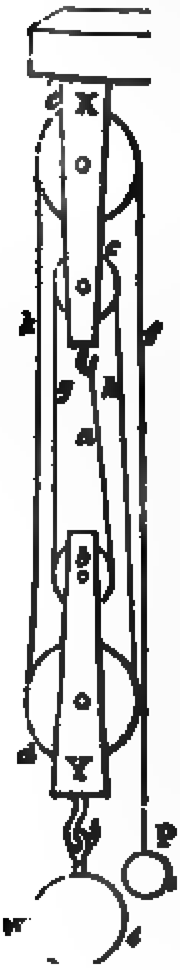


But if a weight *W* hangs at the lower end of the moveable block *p* of the pulley *D*, and the cord *G F* goes under that pulley, it is plain that the half *G* of the cord bears one half of the weight *W*, and the half *F* the other; for they bear the whole between them. Therefore, whatever holds the upper end of either rope, sustains one half of the weight: and if the cord at *F* be drawn up so as to raise the pulley *D* to *C*, the cord will then be extended to its own length, all but that part which goes under the pulley; and consequently, the power that draws the cord will have moved twice as far as the pulley *D* with its weight *W* rises; on which account, a power whose intensity is equal to one half of the weight will be able to support it, because if the power moves (by means of a small addition) its velocity will be double the velocity of the weight; as may be seen by putting the cord over the fixed pulley *C* (which only changes the direction of the power, without giving any advantage to it) and hanging on the weight *P*, which is equal only to one half of the weight *W*; in which case there will be an equilibrium, and a little addition to *P* will cause it to descend, and raise *W* through a space equal to one half of that through which *P* descends. Hence, the advantage gained will be always equal to twice the number of pulleys in the moveable or undermost block. So that, when the upper or fixed block *u* contains two pulleys, which only turn on their axes, and the lower or moveable block *U* contains two pulleys, which not only turn upon their axes, but also rise with the block and

weight; the advantage gained by this is as 4 to the working power. Thus, if one end of the rope *K M O Q* be fixed to a hook at *I*, and the rope passes over the pulleys *N* and *R*, and under the pulleys *L* and *P*, and has a weight *T*, of one pound, hung to its other end at *T*, this weight will balance and support a weight *W* of four pounds hanging by a hook at the moveable block *U*, allowing the said block as a part of the weight. And if as much more power be added, as is sufficient to overcome the friction of the pulleys, the power will descend with four times as much velocity as the weight rises, and consequently through four times as much space.

LECT. II.





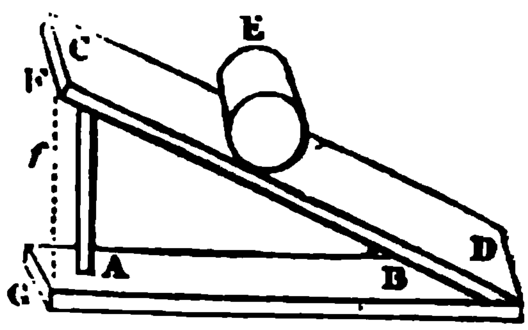
The two pulleys in the fixed block *X*, and the two in the moveable block *Y*, are in the same case with the last mentioned; and those in the lower block give the same advantage to the power.

As a system of pulleys has no great weight, and lies in a small compass, it is easily carried about; and can be applied in a great many cases, for raising weights, where other engines cannot. But they have a great deal of friction on three accounts: 1. Because the diameters of their axes bear a very considerable proportion to their own diameters; 2. Because in working they are apt to rub against one another, or against the sides of the block; 3. Because of the stiffness of the rope that goes over and under them.

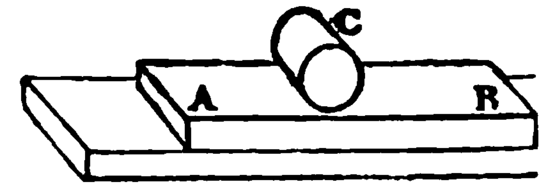
LECT. II.

The inclined plane.

4. The fourth mechanical power is *the inclined plane;* and the advantage gained by it is as great as its length exceeds its perpendicular height. Let *A B* be a plane parallel to the horizon, and *C D* a plane inclined to it; and suppose the whole length *C D* to be three times as great as the perpendicular height *G f F;* in this case, the cylinder *E* will be supported upon the plane *C D,* and kept from rolling down upon it, by a power equal to a third part of the weight of the cylinder. Therefore a weight may be rolled up this inclined plane with a third part of the power which would be sufficient to draw it up by the side of an upright wall. If the plane was four times as long as high, a fourth part of the power would be sufficient; and so on in proportion. Or, if a pillar was to be raised from a floor to the height *G F,* by means of the machine *A B D C,* (which would then act as a half wedge, where the the resistance gives way only on one side) the machine and pillar would be in *equilibrio* when the power applied at *G F* was to the weight of the pillar, as *G F* to *CD;* and if the power be increased, so as to overcome the friction of the machine against the floor and pillar, the machine will be driven, and the pillar raised; and when the machine has moved its whole length upon the floor, the pillar will be raised to the whole height from *G* to *F.*

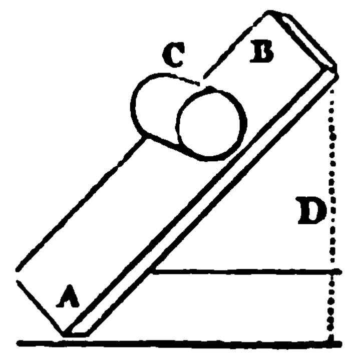


The force wherewith a rolling body descends upon an inclined plane, is to the force of its absolute gravity, by which it would descend perpendicularly in a free space, as the height of the plane is to its length. For, suppose the plane *A B* to be parallel to the horizon, the cylinder *C* will keep at rest upon any part of the plane where it is laid. If the plane be so elevated, that its perpen-

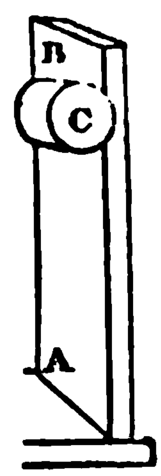


LECT. III.

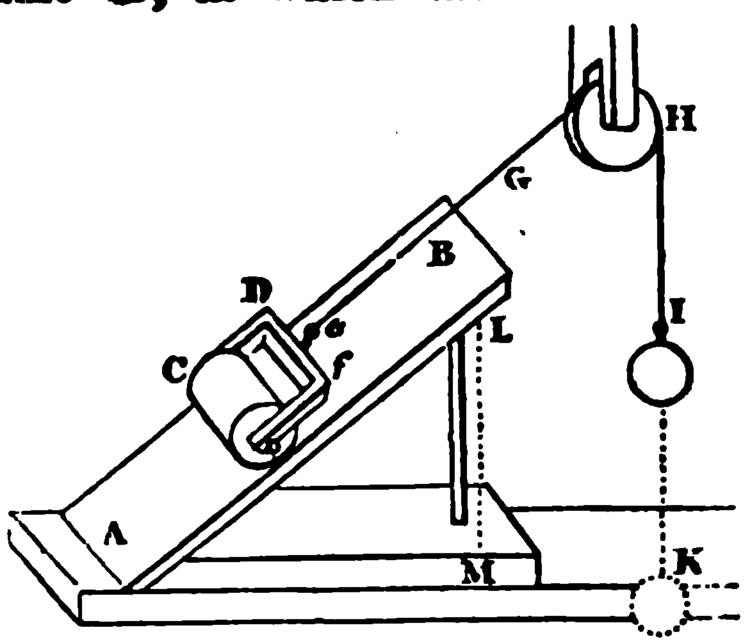
icular height *D* is equal to half its ngth *A B*, the cylinder will roll lown upon the plane with a force qual to half its weight; for it would require a power (acting in the direction of *A B*) equal to half its weight, to keep it from rolling. If the plane *A B*



be elevated, so as to be perpendicular to the horizon, the cylinder *C* will descend with its whole force of gravity, because the plane contributes nothing to its support or hindrance; and therefore, it would require a power equal to its whole weight to keep it from descending.



Let the cylinder *C* be made to turn upon slender pivots in the frame *D*, in which there is a hook *e*, with a line *G* tied to it; let this line go over the fixed pulley *H*, and have its other end tied to the hook in the weight *I*. If the weight of the body *I*, be to the weight of the cylinder *C*,



added to that of its frame *D*, as the perpendicular height of the plane *L M* is to its length *A B*, the weight will just support the cylinder upon the plane, and a small touch of a finger will either cause it to ascend or descend with equal ease: then, if a little addition be made to the weight *I*, it will descend, and draw the cylinder up the plane. In the time that the cylinder moves from *A* to *B*, it will rise through the whole height of the plane *M L*; and the weight will descend from *H* to *K*, through a space equal to the whole length of the plane *A B*.

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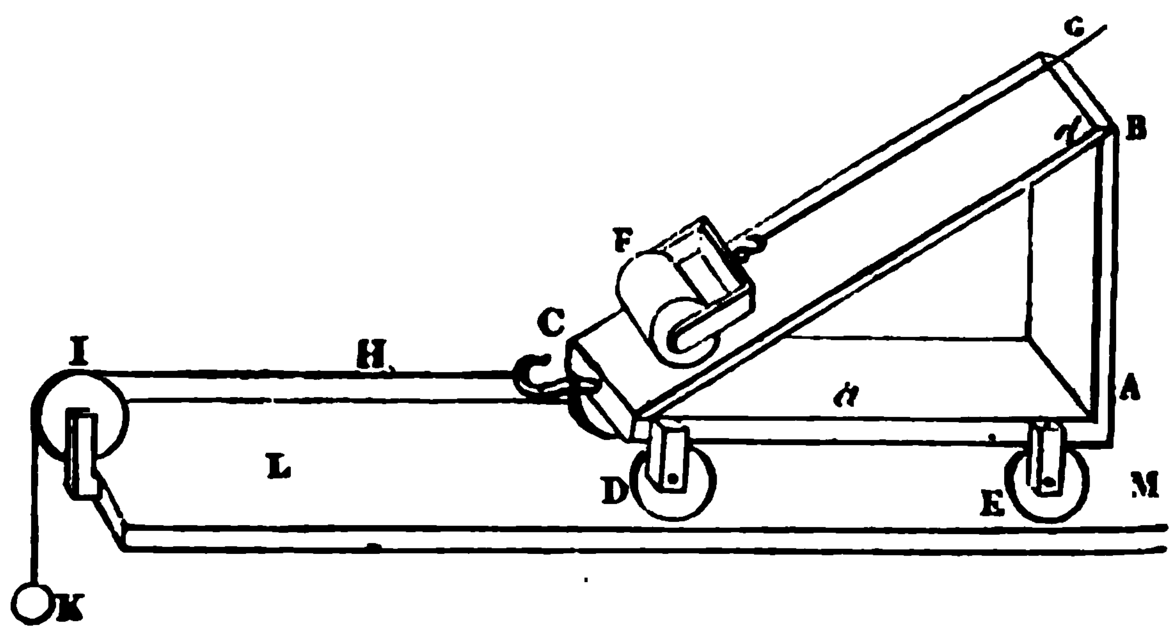
If the machine be made to move upon rollers or friction-wheels, and the cylinder be supported upon the plane *C B* by a line *G* parallel to the plane, a power somewhat less than that which drew the cylinder up the plane will draw the plane under the cylinder, provided the pivots of the axes of the friction-wheels be small, and the wheels themselves be pretty large. For, let the machine *A B C* (equal in length and height to *A B M*,



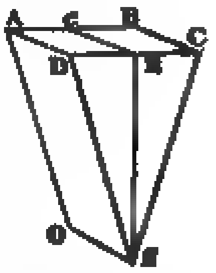
in the previous figure,) move upon four wheels, whereof two appear at *D* and *E*, and the third under *C*, whilst the fourth is hid from sight by the horizontal board *a* : let the cylinder *F* be laid upon the lower end of the inclined plane *C B*, and the line *G* be extended from the frame of the cylinder, about six feet parallel to the plane *C B*; and, in that direction, fixed to a hook in the wall; which will support the cylinder, and keep it from rolling off the plane: let one end of the line *H* be tied to a hook at *C* in the machine, and the other end to a weight *K*, somewhat less than that which drew the cylinder up the plane before:—if this line be put over the fixed pulley *I*, the weight *K* will draw the machine along the horizontal plane *L*, and under the cylinder *F*: and when the machine has been drawn a little more than the whole length *C B*, the cylinder will be raised to *d*, equal to the perpendicular height *A B* above the horizontal part

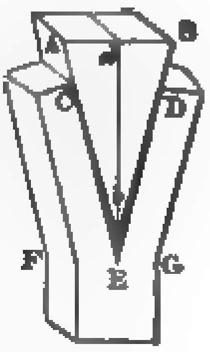
The reason why the machine must be drawn r than the whole length $C\,B$ is, because the weight s perpendicular to $C\,B$. LECT. III.

the inclined plane may be reduced all hatchets, , and other edge-tools which are chamfered only side.

The wedge.

he fifth mechanical power or machine is the which may be considered as two inclined planes $D\,E\,F$ and $C\,E\,F$, together at the bases $e\,E\,F\,O$: C is the whole thickness of the at its back $A\,B\,C\,D$, where the is applied: $E\,F$ is the depth or of the wedge: $D\,F$ the length of its sides, equal to $C\,F$ the length other side; and $O\,F$ is its sharp which is entered into the wood in- to be split by the force of a ham- r mallet striking, perpendicularly back. Thus, $A\,B\,b$ is a wedge into the cleft $C\,D\,E$ of the wood





en the wood does not cleave at any distance be- e wedge, there will be an equilibrium between wer impelling the wedge downward, and the re e of the wood acting against the two sides of dge when the power is to the resistance, as half ickness of the wedge at its back is to the length ier of its sides; because the resistance then acts dicular to the sides of the wedge. But, when the ance on each side acts parallel to the back, the that balances the resistances on both sides will the length of the whole back of the wedge is to its perpendicular height.

en the wood cleaves at any distance before the (as it generally does) the power impelling the

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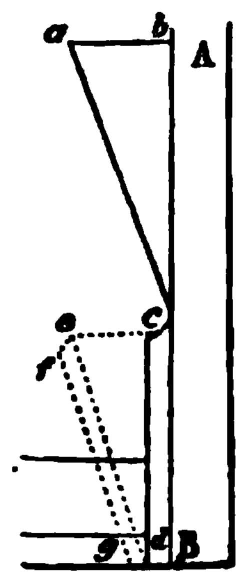
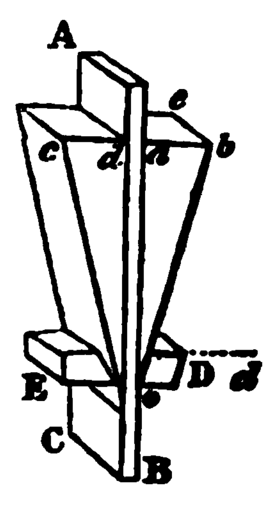
wedge will not be to the resistance of tne wood, as the length of the back of the wedge is to the length of both its sides; but as half the length of the back is to the length of either side of the cleft, estimated from the top or acting part of the wedge. For, if we suppose the wedge to be lengthened down from *b* to the bottom of the cleft at *E*, the same proportion will hold; namely, that the power will be to the resistance, as half the length of the back of the wedge is to the length of either of its sides: or, which amounts to the same thing, as the whole length of the back is to the length of both the sides.

In order to prove what is here advanced concerning the wedge, let us suppose the wedge to be divided lengthwise into two equal parts; and then it will become two equal inclined planes; one of which, as *a b c*, may be made use of as a half wedge for separating the moulding *c d* from the wainscot *A B*. It is evident, that when this half wedge has been driven its whole length *a c* between the wainscot and moulding, its side *a c* will be at *e d*; and the moulding will be separated to *f g* from the wainscot. Now, from what has been already proved of the inclined plane, it appears, that to have an equilibrium between the power impelling the half wedge, and the resistance of the moulding, the former must be to the latter, as *a b* to *a c*; that is, as the thickness of the back which receives the stroke is to the length of the side against which the moulding acts. Therefore, since the power upon the half wedge is to the resistance against its side, as the half back *a b* is to the whole side *a c*, it is plain, that the power upon which the whole wedge (where the whole back is double the half back) must be to the resistance against both its sides, as the thickness



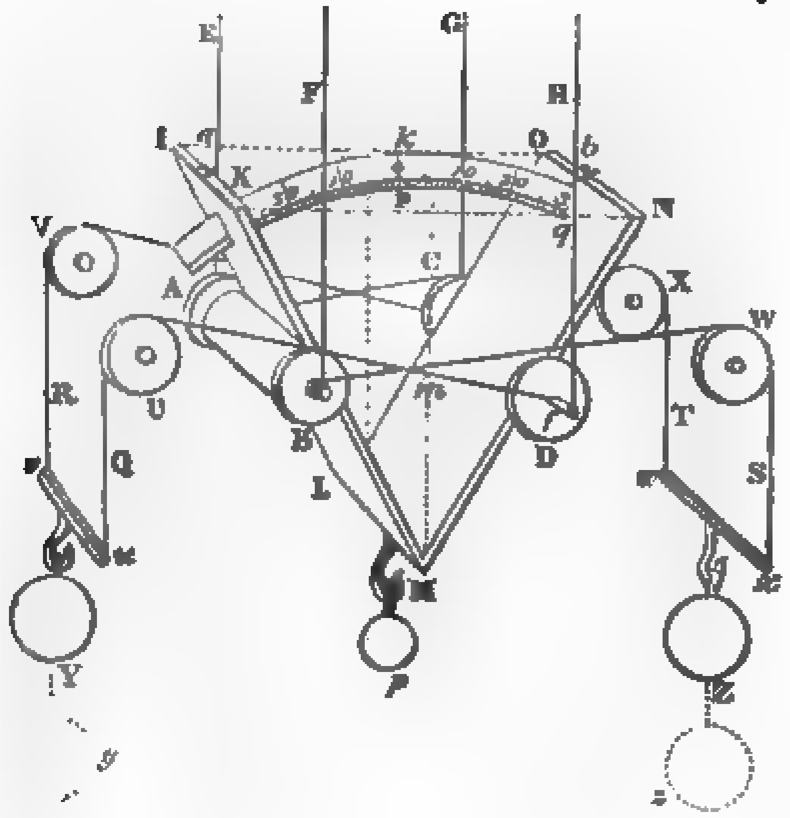
of the whole back is to the length of both the sides; supposing the wedge at the bottom of the cleft: or as the thickness of the whole back to the length of both sides of the cleft, when the wood splits at any distance before the wedge. For, when the wedge is driven quite into the wood, and the wood splits at ever so small a distance before its edge, the top of the wedge then becomes the acting part, because the wood does not touch it any where else. And since the bottom of the cleft must be considered as that part where the whole stickage or resistance is accumulated, it is plain, from the nature of the lever, that the farther the power acts from the resistance, the greater is the advantage.

Some writers have advanced that the power of the wedge is to the resistance to be overcome, as the thickness of the back of the wedge is to the length only of one of its sides; which seems very strange: for, if we suppose *A B* to be a strong inflexible bar of wood or iron fixed into the ground at *C B*, and *D* and *E* to be the two blocks of marble lying on the ground on opposite sides of the bar; it is evident that the block *D* may be separated from the bar to the distance *d*, equal to *a b*, by driving the inclined plane or half wedge *a b o* down between them; and the block *E* may be separated to an equal distance on the other side, in like manner, by the half wedge *c d o*. But the power impelling each half wedge will be to the resistance of the block against its side, as the thickness of that half wedge is to its perpendicular height, because the block will be driven off perpendicular to the side of the bar *A B*. Therefore the power to drive both the half wedges is to both the resistances, as both the half backs is to the perpendicular height of each half wedge. And if the bar be taken away, the blocks put close to-



LECT. III. gether, and the two half wedges joined to make one; it will require as much force to drive it down between the blocks as is equal to the sum of the separate powers acting upon the half wedges when the bar was between them.

To confirm this by an experiment, let two cylinders, as *A B* and *D C*, be drawn towards one another by lines



running over fixed pulleys, and a weight of 40 ounces hanging at the lines belonging to each cylinder: and let a wedge of 40 ounces' weight, having its back just as thick as either of its sides is long, be put between the cylinders, which will then act against each side with a resistance equal to 40 ounces, whilst its own weight endeavours to bring it down and separate them. And here the power of the wedge's gravity impelling it downward, will be to the resistance of both the cylinders against the wedge, as the thickness of the wedge is to double its perpendicular height; for there will then be an equilibrium between the weight of the wedge and the resistance of the cylinders against it, and it will remain at any height between them; requiring just as much power to push it upward as to pull it downward.—If another wedge of

equal weight and depth with this, and only half as thick, be put between the cylinders, it will require twice as much weight to be hung at the ends of the lines which draw them together to keep the wedge from going down between them. That is, a wedge of 40 ounces, whose back is only equal to half its perpendicular height, will require 80 ounces to each cylinder, to keep it in an equilibrium between them: and twice 80 is 160, equal to four times 40. So that the power will be always to the resistance, as the thickness of the back of the wedge is to twice its perpendicular height, when the cylinders move off in a line at right angles to that perpendicular.

The best way, though perhaps not the neatest, that I know of, for making a wedge with its appurtenances for such experiments, is as follows. Let *I K L M* and *L M N O*[34] be two flat pieces of wood, each about fifteen inches long and three or four in breadth, joined together by a hinge at *L M*, and let *P* be a graduated arch of brass, on which the said piece of wood may be opened to any angle not more than 60 degrees, and then fixed at the given angle by means of the two screws *a b*. *I K N O* will represent the back of the wedge, *L M* its sharp edge which enters the wood, and the outsides of the pieces *I K L M* and *L M N O* the two sides of the wedge against which the wood acts in cleaving. By means of the said arch, the wedge may be opened so as to adjust the thickness of its back in any proportion to the length of either of its sides, but not to exceed that length: and any weight, as *p*, may be hung to the wedge upon the hook *M*, which weight, together with the weight of the wedge itself, may be considered as the impelling power; which is all the same in the experiment, whether it be laid upon the back of the wedge, to push it down, or hung to its edge to pull it down.— Let *A B* and *C D* be two wooden cylinders,

Note 34. See Engraving page 72.

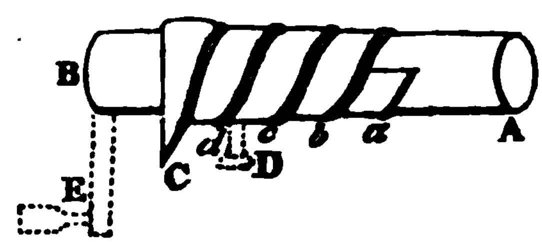
LECT. III. each about two inches thick, where they touch the outsides of the wedge; and let their ends be made like two round flat plates, to keep the wedge from slipping off edgewise from between them. Let a small cord with a loop on one end of it, go over a pivot in the end of each cylinder, and the cords *S* and *T* belonging to the cylinder *A B* go over the fixed pulleys *W* and *X*, and be fastened at their other ends to the bar *w x*, on which any weight as *Z* may be hung at pleasure. In like manner, let the cords *Q* and *R* belonging to the cylinder *B C* go over the fixed pulleys *V* and *U* to the bar *v u*, on which a weight *Y* equal to *Z* may be hung. These weights, by drawing the cylinders towards one another, may be considered as the resistance of the wood acting equally against opposite sides of the wedge; the cylinders themselves being suspended near, and parallel to each other, by their pivots in loops on the lines *E, F, G, H;* which lines may be fixed to hooks in the ceiling of the room. The longer these lines are, the better; and they should never be less than four feet each. The farther also the pulleys *V U* and *X W* are from the cylinders, the truer will the experiments be: and they may turn upon pins fixed into the wall.

In this machine, the weights *Y* and *Z*, and the weight *p*, may be varied at pleasure, so as to be adjusted in proportion of double the wedge's perpendicular height to the thickness of its back; and when they are so adjusted, the wedge will be in *equilibrio* with the resistance of the cylinders.

The wedge is a very great mechanical power, since not only wood wood but even rocks can be split by it; which would be impossible to effect by the lever, wheel and axle, or pulley: for the force of the blow, or stroke, shakes the cohering parts, and thereby makes them separate the more easily.

The *screw*. 6. The sixth and last mechanical power is the *screw;* which cannot properly be called a simple ma-

chine, because it is never used without the application of a lever or winch to assist in turning it: and then it becomes a compound engine of a very great force either in pressing the parts of bodies close together, or in raising great weights. It may be conceived to be made by cutting a piece of paper *A B C* into the form of an inclined plane or half wedge, and then wrapping it round a cylinder *A B*. And here it is evident that the winch *E* must turn the cylinder once round before the weight of resistance *D* can be moved from one spiral winding to another, as from *d* to *c*; therefore, as much as the circumference of a circle described by the handle of the winch is greater than the interval or distance between the spirals, so much is the force of the screw. LECT. III.

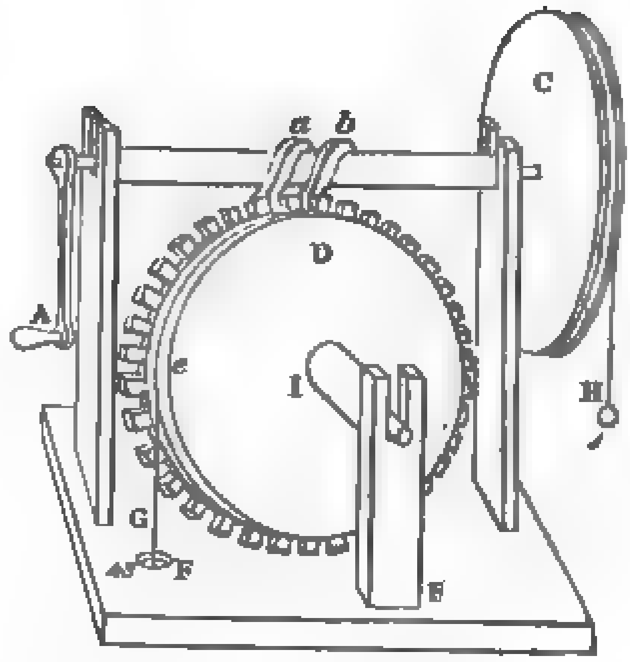


Thus, supposing the distance between the spirals to be half an inch, and the length of the winch to be twelve inches; the circle described by the handle of the winch where the power acts will be 76 inches nearly, or about 152 half inches, and consequently 152 times as great as the distance between the spirals: and therefore a power at the handle, whose intensity is equal to no more than a single pound, will balance 152 pounds acting against the screw; and as much additional force, as is sufficient to overcome the friction, will raise the 152 pounds; and the velocity of the power will be to the velocity of the weight, as 152 to 1. Hence it appears, that the longer the winch be made, and the nearer the spirals are to one another, so much the greater is the force of the screw.

A machine for shewing the force or power of the screw may be contrived in the following manner. Let

LECT. III.

the wheel *C* have a screw *a b* on it axis, working in the teeth of the wheel *D*, which suppose to be 48 in number. It is plain, that for every time the wheel *C* and screw *ab* are turned round by the winch *A*, the wheel *D* will be moved one tooth by the screw; and



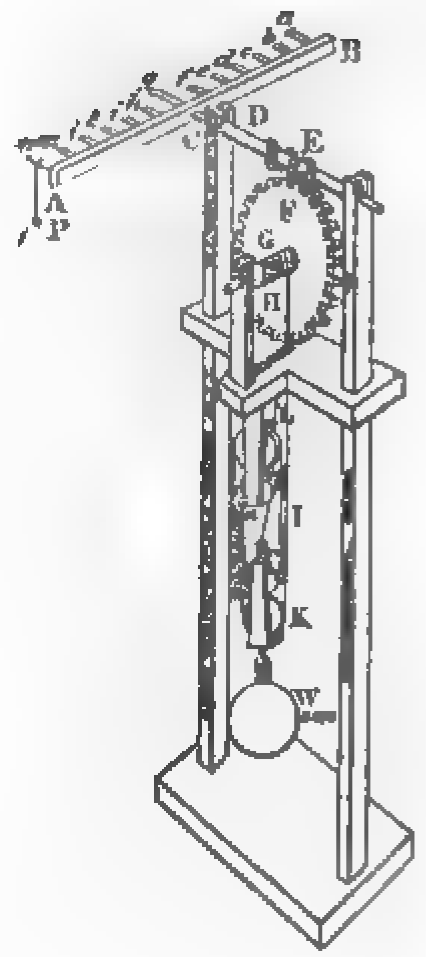
therefore, in 48 revolutions of the winch, the wheel *D* will be turned once round. Then, if the circumference of a circle described by the handle of the winch *A* be equal to the circumference of a groove *e* round the wheel *D*, the velocity of the handle will be 48 times as great as the velocity of any given point in the groove. Consequently, if a line *G* (above number 48) goes round the groove *e*, and has a weight of 48 pounds hung to it below the pedestal *F F*, a power equal to one pound at the handle will balance and support the weight.—To prove this by experiment, let the circumferences of the grooves of the wheels *C* and *D* be equal to one another; and then if a weight *H* of one pound be suspended by a line going round the groove of the wheel *C*, it will balance a weight of 48 pounds hanging by the line *G*; and a small addition to the weight *H* will cause it to descend, and so raise up the other weight.

If the line *G*, instead of going round the groove *e* of the wheel *D*, goes round its axle *I*; the power of the machine will be as much increased, as the circumference of the groove *e* exceeds the circumference of the axle: which, supposing it to be six times, then one pound at

H will balance 6 times 48, or 288 pounds hung to the line on the axle: and hence the power or advantage of this machine will be as 288 to 1. That is to say, a man, who by his natural strength could lift a hundred weight, will be able to raise 288 hundred, or 14 $\frac{4}{5}$ ton weight by this engine.

But the following engine is still more powerful, on account of its having the addition of four pulleys: and in it we may look upon all the mechanical powers as combined together, even if we take in the balance. For as the axis *D* of the bar *A B* is in its middle at *C*, it is plain that if equal weights are suspended upon any two pins equidistant from the axis *C*, they will counterpoise each other.—It becomes a lever by hanging a small weight *P* upon the pin *a*, and a weight as much heavier upon either of the pins *b*, *c*, *d*, *e*, or *f*, as is in proportion to the pins being so much nearer the axis. The wheel and axle *F G* is evident; so is the screw *E* which takes in the inclined plane, and with it the half wedge. Part of a cord goes round the axle, the rest under the lower pulleys *K*, *m*, over the upper pulleys *L*, *n*, and then it is tied to a hook at *m* in the lower or moveable block, on which hangs the weight *W*.

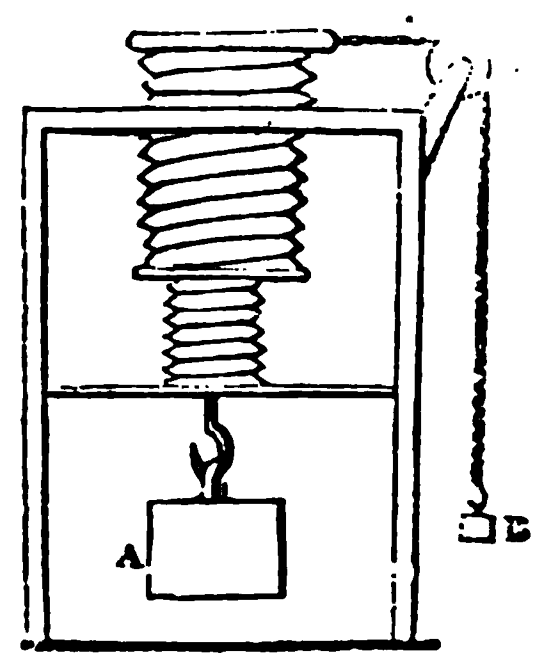
A combination of all the mechanical powers.



In this machine, if the wheel *F* has 30 teeth, it will be turned once round in thirty revolutions of the bar *A B*, which is fixed on the axis *D* of the screw *E*: if the length of the bar is equal to twice the diameter of the wheel, the pins *a* and *n* at the ends of the bar will move

LECT. III. 60 times as fast as the teeth of the wheel do: and consequently, one ounce at P will balance 60 ounces hung upon a tooth at q in the horizontal diameter of the wheel. Then, if the diameter of the wheel F is 10 times as great as the diameter of the axle G, the wheel will have 10 times the velocity of the axle; and therefore one ounce P at the end of the lever $A\ C$ will balance 10 times 60, or 600 ounces hung to the rope H which goes round the axle. Lastly, if four pulleys be added, they will make the velocity of the lower block K, and weight W, four times less than the velocity of the axle: and this being the last power in the machine, which is four times as great as that gained by the axle, it makes the whole power of the machine 4 times 600, or 2400. So that a man who could lift one hundred weight in his arms by his natural strength, would be able to raise 2400 times as much by this engine.—But it is here as in all other mechanical cases; for the time lost is always as much as the power gained, because the velocity with which the power moves will ever exceed the velocity with which the weight rises, as much as the intensity of the weight exceeds the intensity of the power.[35]

Note 35. The screw suggested by Mr. Hunter is too valuable to be passed over, while enumerating the modifications of this mechanical power. The apparatus, as the annexed diagram will shew, consists of a double screw, or rather of two screws, one of which moves within the other, and as the inner screw is made finer than that which turns on it, the power is very considerable. In the above illustration it is so made that the distance between the threads of the interior screw is four fifths of that of the exterior or perforated part, and this distance is one thirtieth of the circumference, so that the weight B is capable of supporting 150 pounds at A.

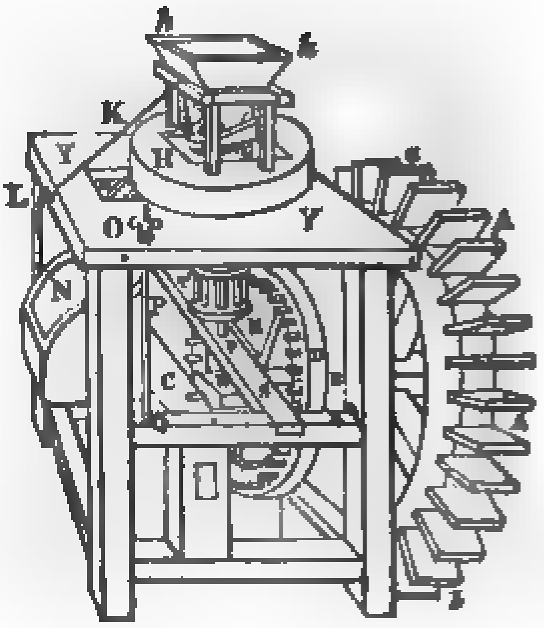


LECTURE IV.

ILLS, CRANES, WHEEL-CARRIAGES, AND THE ENGINE FOR DRIVING PILES.

e engines are so universally useful, it would be us to make any apology for describing them.[*] common *breast-mill*, where the fall of water may t ten feet, *A A* great wheel, generally about 8 feet in diame-koned from the st edge of any rd at *a* to that posite float at *b*. wheel the water eyed through a , and by falling e wheel, turns it

A common mill.



he axis *B B* of this wheel, and within the mill is a wheel *D*, about 8 or 9 feet diameter, having , which turn a trundle *E* containing ten upright or rounds; and when these are the number of d rounds, the trundle will make 6 $\frac{1}{a}$ revolutions revolution of the wheel.

trundle is fixed upon a strong iron axis called ndle, the lower end of which turns in a brass xed at *F*, in the horizontal beam *S T* called the tree; and the upper part of the spindle turns in en bush fixed into the nether millstone, which

6. The various modes of applying water as a prime mover ales will be fully examined at the end of this Lecture.

LECT. IV. lies upon beams in the floor *Y Y*. The top part of the spindle above the bush is square, and goes into a square hole in a strong iron cross *a b c d*, called the rynd; under which, and close to the bush, is a round piece of thick leather upon the spindle, which it turns round at the same time as it does the rynd.

The rynd is let into grooves in the under surface of the running millstone *G* (p. 79.) and so turns it round in the same time that the trundle *E* is turned round by the cog-wheel *D*. This mill-stone has a large hole quite through its middle, called the eye of the stone, through which the middle part of the rynd and upper end of the spindle may be seen; whilst the four ends of the rynd lie hid below the stone in their grooves.

The end *T* of the bridge-tree *T S* (which supports the upper millstone *G* upon the spindle) is fixed into a hole in the wall; and the end *S* is let into a beam *Q R* called the brayer, whose end *R* remains fixed in a mortise: and its other end *Q* hangs by a strong iron rod *P* which goes through the floor *Y Y*, and has a screw-nut on its top at *O*; by the turning of which nut, the end *Q* of the brayer is raised or depressed at pleasure; and consequently the bridge-tree *T S* and upper mill-stone. By this means, the upper mill-stone may be set as close to the under one, or raised as high from it, as the miller pleases. The nearer the millstones are to one another, the finer they grind the corn, and the more remote from one another, the coarser.

The upper millstone *G* is inclosed in a round box *H*, which does not touch it any where; and is about an inch distant from its edge all around. On the top of this box stands a frame for holding the hopper *k k*, to which is hung the shoe *I* by two lines fastened to the hind-part of it, fixed upon hooks in the hopper, and by one end of the crook-string *K* fastened to the fore-part

of it at *i;* the other end being twisted round the pin *L.* As the pin is turned one way, the string draws up the shoe closer to the hopper, and so lessens the aperture between them; and as the pin is turned the other way, it lets down the shoe, and enlarges the aperture.

If the shoe be drawn up quite to the hopper, no corn can fall from the hopper into the mill; if it be let a little down, some will fall: and the quantity will be more or less, according as the shoe is more or less let down. For the hopper is open at bottom, and there is a hole in the bottom of the shoe, not directly under the bottom of the hopper, but forwarder towards the end *i,* over the middle of the eye of the millstone.

There is a square hole in the top of the spindle, in which is put the feeder *e:* (see engraving, page 80.) this feeder (as the spindle turns round) jogs the shoe three times in each revolution, and so causes the corn to run constantly down from the hopper through the shoe, into the eye of the millstone, where it falls upon the top of the rynd, and is, by the motion of the rynd, and the leather under it, thrown below the upper stone, and ground between it and the lower one. The violent motion of the stone creates a centrifugal force in the corn going round with it, by which means it gets farther and farther from the center, as in a spiral, in every revolution, until it be thrown quite out; and, being then ground, it falls through a spout *M,* called the mill-eye, into the trough *N.*

When the mill is fed too fast, the corn bears up the stone, and is ground too coarse; and besides, it clogs the mill so as to make it go too slow. When the mill is too slowly fed, it goes too fast, and the stones by their attrition are apt to strike fire against one another. Both which inconveniences are avoided by turning the pin *L* backwards or forwards, which draws up or lets

LECT. IV. down the shoe; and so regulates the feeding as t miller sees convenient.

The heavier the running millstone is, and the great the quantity of water that falls upon the wheel, so mu the faster will the mill bear to be fed; and consequent so much the more it will grind. And on the contrar the lighter the stone, and the less the quantity of wat so much slower must the feeding be. But when t stone is considerably worn, and become light, the mi must be fed slowly at any rate; otherwise the stone wi be too much borne up by the corn under it, which wil make the meal coarse.

The quantity of power required to turn a heavy mill stone, is but very little more than what is sufficient t turn a light one: for as it is supported upon the spindl by the bridge-tree *S T*, and the end of the spindle tha turns in the brass foot therein being but small, the odd arising from the weight is but very inconsiderable in it action against the power or force of the water. An besides, a heavy stone has the same advantage as a heav fly; namely, that it regulates the motion much bette than a light one.

In order to cut and grind the corn, both the uppe and under millstones have channels or furrows cut int them, proceeding obliquely from the center towards th circumference. And these furrows are cut perpendicularly on one side and obliquely on the other into the stone, which gives each furrow a sharp edge, and in the two stones they come, as it were, against one another like the edges of a pair of scissars: and so cut the corn, to make it grind the easier when it falls upon the places between the furrows. These are cut the same way in both stones when they lie upon their backs, which makes them run cross ways to each other, wher the upper stone is inverted by turning its furrowed sur

face towards that of the lower. For, if the furrows of both stones lay the same way, a great deal of the corn would be driven onward in the lower furrows, and so come out from between the stones without being either cut or bruised. LECT IV.

When the furrows become blunt and shallow by wearing, the running stone must be taken up, and both stones new drest with a chisel and hammer. And every time the stone is taken up, there must be some tallow put round the spindle upon the bush, which will soon be melted by the heat the spindle acquires from its turning and rubbing against the bush, and so will get in betwixt them: otherwise the bush would take fire in a very little time.

The bush must embrace the spindle quite close, to prevent any shake in the motion, which would make some parts of the stones grate and fire against each other; whilst other parts of them would be too far asunder, and by that means spoil the meal in grinding.

Whenever the spindle wears the bush so as to begin to shake in it, the stone must be taken up, and a chisel drove into several parts of the bush; and when it is taken out, wooden wedges must be driven into the holes; by which means the bush will be made to embrace the spindle close all around it again. In doing this, great care must be taken to drive equal wedges into the bush on opposite sides of the spindle; otherwise it will be thrown out of the perpendicular, and so hinder the upper stone from being set parallel to the under one, which is absolutely necessary for making good work. When any accident of this kind happens, the perpendicular position of the spindle must be restored by adjusting the bridge-tree *S T* by proper wedges put be-between it and the brayer *Q R*.

It often happens, that the rynd is a little wrenched in laying down the upper stone upon it; or is made to sink

LECT. IV. a little lower upon one side of the spindle than on the other; and this will cause one edge of the upper stone to drag all around upon the other, whilst the opposite edge will not touch. But this is easily set to rights, by raising the stone a little with a lever, and putting bits of paper, cards, or thin chips, between the rynd and the stone.

The diameter of the upper stone is generally about six feet, the lower stone about an inch more: and the upper stone, when new, contains about 22½ cubic feet, which weighs somewhat more than 1900 pounds. A stone of this diameter ought never to go more than 60 times round in a minute; for if it turns faster, it will heat the meal.

The grinding surface of the under stone is a little convex from the edge to the center, and that of the upper stone a little more concave: so that they are farthest from one another in the middle, and come gradually nearer towards the edges. By this means, the corn at its first entrance between the stones is only bruised; but as it goes farther on towards the circumference or edge, it is cut smaller and smaller; and at last finely ground just before it comes out from between them.

The water-wheel must not be too large, for if it be, its motion will be two slow; nor too little, for then it will want power. And for a mill to be in perfection, the floats of the wheel ought to move with a third part of the velocity of the water, and the stone to run round once in a second of time.

In order to construct a mill in this perfect manner, observe the following rules:

1. Measure the perpendicular height of the fall of water, in feet, above that part of the wheel on which the water begins to act; and call that, the height of the fall.

2. Multiply this constant number 64.2882 by the

height of the fall in feet, and the square root of the product shall be the velocity of the water at the bottom of the fall, or the number of feet that the water there moves *per* second. LECT. IV.

3. Divide the velocity of the water by 3, and the quotient shall be the velocity of the floatboards of the wheel; or the number of feet they must each go through in a second, when the water acts upon them so, as to have the greatest power to turn the mill.

4. Divide the circumference of the wheel in feet by the velocity of its floats in feet *per* second, and the quotient shall be the number of seconds in which the wheel turns round.

5. By this last number of seconds divide 60; and the quotient shall be the number of turns of the wheel in a minute.

6. Divide 60 (the number of revolutions the millstone ought to have in a minute) by the number of turns of the wheel in a minute, and the quotient shall be the number of turns the millstone ought to have for one turn of the wheel.

7. Then, as the number of turns of the wheel in a minute is to the number of turns of the millstone in a minute, so must the number of staves in the trundle be to the number of cogs in the wheel, in the nearest whole numbers that can be found.

By these rules I have calculated the following table to a water-wheel 18 feet diameter, which I apprehend may be a good size in general.

To construct a mill by this table, find the height of the fall of water in the first column, and against that height, in the sixth column, you have the number of cogs in the wheel, and staves in the trundle, for causing the millstone to make about 60 revolutions in a minute, as near as possible, when the wheel goes with a third part of the velocity of the water. And it appears by the

LECT. V. 7th column, that the number of cogs in the wheel, and staves in the trundle, are so near the truth for the required purpose, that the least number of revolutions of the millstone in a minute is between 59 and 60, and the greatest number never amounts to 61.

The MILL-WRIGHT'S TABLE.

Height of the fall of water.	Velocity of the water per second.		Velocity of the wheel per second.		Revolutions of the wheel per minute.		Revolutions of the mill-stone for one of the wheel.		Cogs in the wheel and staves in the trundle.		Revolu. of the mill-stone per min. by these cogs and staves.	
Feet.	Feet.	100 parts of a foot.	Feet.	100 parts of a foot.	Rev.	100 parts of a Rev.	Rev.	100 parts of a Rev	Cogs.	Staves.	Rev.	100 parts of a Rev.
1	8	.02	2	.67	2	.83	21	.20	127	6	59	.92
2	11	.34	3	.78	4	.00	15	.00	105	7	60	.00
3	13	.89	4	.63	4	.91	12	.22	98	8	60	.14
[illegible]	16	.04	5	.35	5	.67	10	.58	95	9	59	.87
5	17	.93	5	.98	6	.34	9	.46	85	9	59	.84
6	19	.64	6	.55	6	.94	8	.64	78	9	60	.10
7	21	.21	7	.07	7	.50	8	.00	72	9	60	.00
8	22	.68	7	.56	8	.02	7	.48	67	9	59	.67
9	24	.05	8	.02	8	.51	7	.05	70	10	59	.57
10	25	.35	8	.45	8	.97	6	.69	67	10	60	.09
11	26	.59	8	.86	9	.40	6	.38	64	10	60	.16
12	27	.77	9	.26	9	.82	6	.11	61	10	59	.90
13	28	.91	9	.64	10	.22	5	.87	59	10	60	.18
14	30	.00	10	.00	10	.60	5	.66	56	10	59	.36
15	31	.05	10	.35	10	.99	5	.46	56	10	60	.48
16	32	.07	10	.69	11	.34	5	.29	53	10	60	.10
17	33	.06	11	.02	11	.70	5	.13	51	10	59	.67
18	34	.02	11	.34	12	.02	4	.99	50	10	60	.11
19	34	.95	11	.65	12	.37	4	.85	49	10	60	.61
20	35	.86	11	.95	12	.68	4	.73	47	10	59	.59
1	2		3		4		5		6		7	

Such a mill as this, with a fall of water about 7½ feet

will require about 32 hogsheads every minute to turn the wheel with a third part of the velocity with which the water falls; and to overcome the resistance arising from the friction of the geers and attrition of the stones in grinding the corn.

The greater fall the water has, the less quantity of it will serve to turn the mill. The water is kept up in the mill-dam, and let out by a sluice called the penstock, when the mill is to go. When the penstock is drawn up by means of a lever, it opens a passage through which the water flows to the wheel: and when the mill is to be stopped, the penstock is let down, which stops the water from falling upon the wheel.

A less quantity of water will turn an overshot-mill, (where the wheel has buckets instead of float-boards) than a breast-mill, where the fall of the water seldom exceeds half the height *A b* of the wheel. So that, where there is but a small quantity of water, and a fall great enough for the wheel to lie under it, the bucket (or overshot) wheel is always used. But where there is a large body of water, with a little fall, the breast or float-board wheel must take place. Where the water runs only upon a little declivity, it can act but slowly upon the under part of the wheel at *b;* in which case, the motion of the wheel will be very slow: and therefore the floats ought to be very long, though not high, that a large body of water may act upon them; so that what is wanting in velocity may be made up in power; and then the cog-wheel may have a greater number of cogs in proportion to the rounds in the trundle, in order to give the millstone a sufficient degree of velocity.

They who have read what is said in the first Lecture, concerning the acceleration of bodies falling freely by the power of gravity acting constantly and uniformly upon them, may perhaps ask, Why should the motion of the wheel be equable, and not accelerated, since the

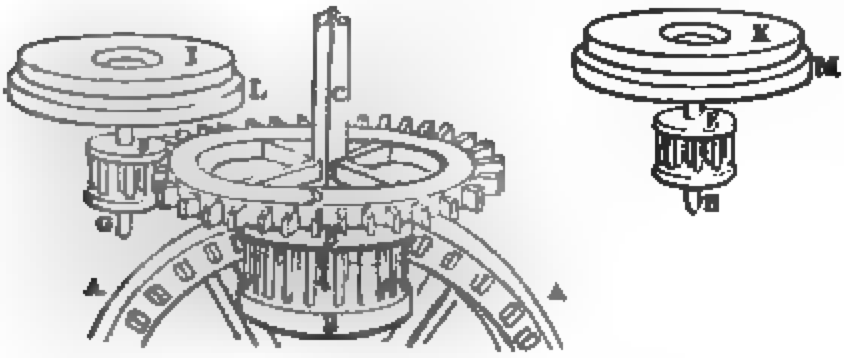
LECT. IV. water acts constantly and uniformly upon it? The plain answer is, That the velocity of the wheel can never be so great as the velocity of the water that turns it; for, if it should become so great, the power of the water would be quite lost upon the wheel, and then there would be no proper force to overcome the friction of the geers and attrition of the stones. Therefore, the velocity with which the wheel begins to move, will increase no longer than till its *momentum* or force is balanced by the resistance of the working parts of the mill; and then the wheel will go on with an equable motion.

A *hand-mill.* [If the cog-wheel *D* be made about 18 inches diameter, with 30 cogs, the trundle as small in proportion, with 10 staves, and the millstones be each about two feet in diameter, and the whole work be put into a strong frame of wood, as represented in the figure, the engine will be a hand-mill for grinding corn or malt in private families. And then, it may be turned by a winch instead of the wheel *A A*: the millstone making three revolutions for every one of the winch. If a heavy fly be put upon the axle *B*, near the winch, it will help to regulate the motion.]

If the cogs of the wheel and rounds of the trundle could be put in as exactly as the teeth are cut in the wheels and pinions of a clock, then the trundle might divide the wheel exactly: that is to say, the trundle might make a given number of revolutions for one of the wheel, without a fraction. But as any exact number is not necessary in mill-work, and the cogs and rounds cannot be set in so truly as to make all the intervals between them equal; a skilful mill-wright will always give the wheel what he calls a *hunting cog;* that is, one more than what will answer to an exact division of the wheel by the trundle. And then, as every cog comes to the trundle, it will take the next staff or round behind the one which it took in the former revolution: and by

that means, will wear all the parts of the cogs and rounds which work upon one another equally, and to equal distances from one another in a little time; and so make a true uniform motion throughout the whole work. Thus, in the above water-mill, the trundle has 10 staves, and the wheel 61 cogs. LECT. IV.

Sometimes, where there is a sufficient quantity of



water, the cog-wheel *A A* turns a large trundle *B B*, on whose axis *C* is fixed the horizontal wheel *D*, with cogs all around its edge, turning two trundles *E* and *F* at the same time; whose axes or spindles *G* and *H* turn two millstones *I* and *K*, upon the fixed stones *L* and *M*. And when there is not work for them both, either may be made to lie quiet, by taking out one of the staves of its trundle, and turning the vacant place towards the cog-wheel *D*. And there may be a wheel fixed on the upper end of the great upright axle *C* for turning a couple of boulting-mills; and other work for drawing up the sacks, fanning and cleaning the corn, sharpening of tools, &c.

If, instead of the cog-wheel *A A* and trundle *B B*, horizontal levers be fixed into the axle *C*, below the wheel *D*; then, horses may be put to these levers for turning the mill: which is often done where water cannot be had for that purpose. *A horse-mill.*

The working parts of a wind-mill differ very little from those of a water-mill; only the former is turned *A wind mill.*

by the action of the wind upon four sails, every one of which ought (as is generally believed) to make an angle of 54¾ degrees with a plane perpendicular to the axis on which the arms are fixed for carrying them. It being demonstrable, that when the sails are set to such an angle, and the axis turned end-ways toward the wind, the wind has the greatest power upon the sails. But this angle answers only to the case of a vane or sail just beginning to move:[37] for, when the vane has a certain degree of motion, it yields to the wind; and then that angle must be increased to give the wind its full effect.

Again, the increase of this angle should be different, according to the different velocities from the axis to the extremity of the vane. At the axis it should be 54¾ degrees, and thence continually decrease, giving the vane a twist, and so causing all the ribs of the vane to lie in different planes.

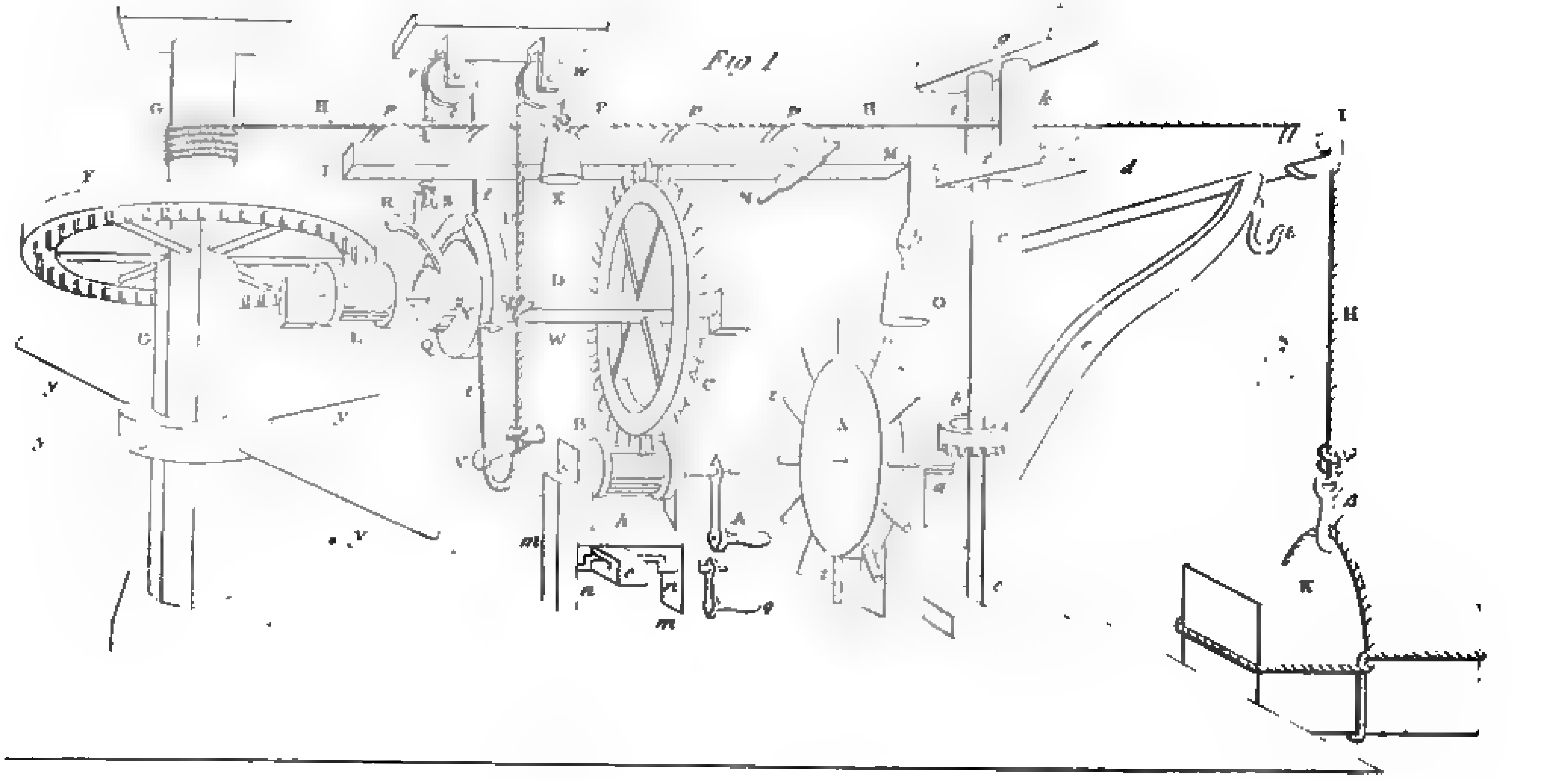
Lastly, These ribs ought to decrease in length from the axis to the extremity, giving the vane a curvilineal form; so that no part of the force of any one rib be spent upon the rest, but all move on independent of each other. All this is required to give the sails of a windmill their true form: and we see both the twist and the diminution of the ribs exemplified in the wings of birds.

It is almost incredible to think with what velocity the tips of the sails move when acted upon by a moderate gale of wind. I have several times counted the number of revolutions made by the sails in ten or fifteen minutes; and from the length of the arms from tip to tip, have computed, that if a hoop of that diameter was to run upon the ground with the same velocity that it would move if put upon the sail-arms, it would go upwards of 30 miles in an hour.

Note 37. See MACLAURIN's Fluxions, near the end.

CRANE.

PLATE. II



G Gladwin sculp^t

s the ends of the sails nearest the axis cannot move the same velocity that the tips or farthest ends do, ugh the wind acts equally strong upon them; per- a better position than that of stretching them the arms directly from the center of motion, might have them set perpendicularly across the farther of the arms, and there adjusted lengthwise to the r angle. For, in that case, both ends of the sails l move with the same velocity; and being farther the center of motion, they would have so much ore power: and then, there would be no occasion iving them so large as they are generally made; would render them lighter, and consequently, there be so much the less friction on the thick neck of de where it turns in the wall. LECT IV

crane is an engine by which great weights are l to certain heights, or let down to certain depths. sists of wheels, axles, pulleys, ropes, and a gib or t. When the rope *H* (Plate II.) is hooked to the t *K*, a man turns the winch *A*, on the axis where- the trundle *B*, which turns the wheel *C*, on whose) is the trundle *E*, which turns the wheel *F* with right axis *G*, on which the great rope *H H* winds wheel turns: and going over a pulley *I* at the f the arm *d* of the gib *c c d e*, it draws up the burden *K*; which, being raised to a proper t, as from a ship to the quay, is then brought over ay by pulling the wheel *Z* round by the handles which turns the gib by means of the half wheel *b* on the gib-post *c c*, and the strong pinion *a* fixed on is of the wheel *Z*. This wheel gives the man that it an absolute command over the gib, so as to nt it from taking any unlucky swing, such as often ns when it is only guided by a rope tied to its arm d people are frequently hurt, sometimes killed, by accidents. A *crane*

LECT. IV.

The great rope goes between two upright rollers *i* and *k*, which turn upon gudgeons in the fixed beams *f* and *g*; and as the gib is turned towards either side, the rope bends upon the roller next that side. Were it not for these rollers, the gib would be quite unmanageable; for the moment it were turned ever so little towards any side, the weight *K* would begin to descend, because the rope would be shortened between the pulley *I* and axis *G*; and so the gib would be pulled violently to that side, and either be broken to pieces, or break every thing that came in its way. These rollers must be placed so, that the sides of them, round which the rope bends, may keep the middle of the bended part directly even with the center of the hole in which the upper gudgeon of the gib turns in the beam *f*. The truer these rollers are placed, the easier the gib is managed, and the less apt to swing either way by the force of the weight *K*.

A ratchet-wheel *Q* is fixed upon the axis *D*, near the trundle *E*; and into this wheel the catch or click *R* falls. This hinders the machinery from running back by the weight of the burden *K*, if the man who raises it should happen to be careless, and so leave off working at the winch *A* sooner than he ought to do.

When the burden *K* is raised to its proper height from the ship, and brought over the quay by turning the gib about, it is let down gently upon the quay, or into a cart standing thereon, in the following manner: A man takes hold of the rope *t t* (which goes over the pulley *v*, and is tied to a hook at *S* in the catch *R*) and so disengages the catch from the ratchet-wheel *Q*; and then, the man at the winch *A* turns it backward, and lets down the weight *K*. But if the weight pulls too hard against this man, another lays hold of the handle *V*, and by pulling it downward, draws the gripe *U* close to the wheel *Y*, which, by rubbing hard against the gripe, hinders the too quick descent of the weight; and

not only so, but even stops it at any time, if required. By this means, heavy goods may be either raised or let down at pleasure, without any danger of hurting the men who work the engine.

When part of the goods are craned up, and the rope is to be let down for more, the catch *R* is first disengaged from the ratchet-wheel *Q*, by pulling the cord *t*; then the handle *q* is turned half round backward, which, by the crank *n n* in the piece *o*, pulls down the frame *h* between the guides *m* and *m* (in which it slides in a groove) and so disengages the trundle *B* from the wheel *C*: and then, the heavy hook *β* at the end of the rope *H* descends by its own weight, and turns back the great wheel *F* with its trundle *E*, and the wheel *C*; and this last wheel acts like a fly against the wheel *F* and hook *β*; and so hinders it from going down too quick; whilst the weight *X* keeps up the gripe *U* from rubbing against the wheel *Y*, by means of a cord going from the weight, over the pulley *w* to the hook *W* in the gripe; so that the gripe never touches the wheel, unless it be pulled down by the handle *V*.

When the crane is to be set at work again, for drawing up another burden, the handle *q* is turned half round forwards; which by the crank *n n*, raises up the frame *h*, and causes the trundle *B* to lay hold of the wheel *C*; and then, by turning the winch *A*, the burden of goods *K* is drawn up as before.

The crank *n n* turns pretty stiff in the mortise near *o*, and stops against the farther end of it when it has got just a little beyond the perpendicular; so that it can never come back of itself: and therefore, the trundle *B* can never come away from the wheel *C*, until the handle *q* be turned half round, backwards.

The great rope runs upon rollers in the lever *L M*, which keeps it from bending between the axle at *G* and the pulley *I*. This lever turns upon the axis *N* by means

LECT. IV. of the weight O, which is just sufficient to keep its end L up to the rope: so that, as the great axle turns, and the rope coils round it, the lever rises with the rope, and prevents the coilings from going over one another.

The power of this crane may be estimated thus: suppose the trundle B to have 13 staves or rounds, and the wheel C to have 78 spur cogs; the trundle E to have 14 staves, and the wheel F 56 cogs. Then, by multiplying the staves of the trundles, 13 and 14, into one another, their product will be 182; and by multiplying the cogs of the wheels, 78 and 56, into one another, their product will be 4368, and dividing 4368 by 182, the quotient will be 24; which shews that the winch A makes 24 turns for one turn of the wheel F and its axle G on which the great rope or chain $H I H$ winds. So that, if the length or radius of the winch A were only equal to half the diameter of the great axle G, added to half the thickness of the rope H, the power of the crane would be as 24 to 1: but the radius of the winch being double the above length, it doubles the said power, and so makes it as 48 to 1: and in which case, a man may raise 48 times as much weight by this engine as he could do by his natural strength without it, making proper allowance for the friction of the working parts.—Two men may work at once, by having another winch on the opposite end of the axis of the trundle under B; and so make the power still double.

If this power be thought greater than what may be generally wanted, the wheels may be made with fewer cogs in proportion to the staves in the trundles; and so the power may be of whatever degree is judged to be requisite. But if the weight be so great as will require yet more power to raise it (suppose a double quantity) then the rope H may be put under a moveable pulley, as δ, and the end of it tied to a hook in the gib at ϵ; which will give a double power to the machine, and so raise a

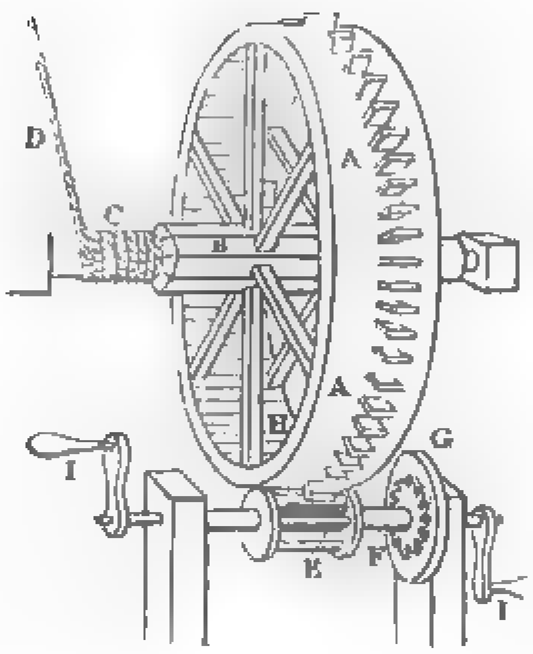
double weight hooked to the block of the moveable pulley. LECT. III.

When only small burthens are to be raised, this may be quickly done by men pushing the axle G round by the handspokes y, y, y, y: having first disengaged the trundle B from the wheel C: and then, this wheel will only act as a fly upon the wheel F; and the catch R will prevent its running back, if the men should inadvertently leave off pushing before the burthen be unhooked from β.

Lastly. When very heavy burthens are to be raised, which might endanger the breaking of the cogs in the wheel F, their force against these cogs may be much abated by men pushing round the handspokes y, y, y, y, whilst the man at A turns the winch.

I have only shewn the working parts of this crane, without the whole of the beams which support them; knowing that these are easily supposed, and that if they had been drawn, they would have hid a great deal of the working parts from sight, and also confused the figure.

Another very good *crane* is made in the following manner. *A A* is a great wheel turned by men walking within it at *H*. On the part *C*, of its axle *B C*, the great rope *D* is wound as the wheel turns; and this rope draws up goods in the same way as the rope *H H* does in the abovementioned crane, the gib-work here being supposed to be of the same sort. But these cranes are very danger- Another crane.



LECT. IV. ous to the men in the wheel; for, if any of the men should chance to fall, the burthen will make the wheel run back, and throw them all about within it; which often breaks their limbs, and sometimes kills them. The late ingenious *Mr. Padmore* of Bristol, (whose contrivance the forementioned crane is, so far as I can remember its construction, after seeing it once about twelve years ago,[38]) observing this dangerous construction, contrived a method for remedying it, by putting cogs all around the outside of the wheel, and applying a trundle *E* to turn it; which increases the power as much as the number of cogs in the wheel is greater than the number of staves in the trundle: and by putting a ratchet-wheel *F* on the axis of the trundle, (as in the above-mentioned crane) with a catch to fall into it, the great wheel is stopped from running back by the force of the weight, even if all the men in it should leave off walking. And by one man working at the winch *I*, or two men at the opposite winches when needful, the men in the wheel are much assisted, and much greater weights are raised, than could be by men only within the wheel. *Mr. Padmore* put also a gripe wheel *G* upon the axis of the trundle, which being pinched in the same manner as described in the former crane, heavy burthens may be let down without the least danger. And before this contrivance, the lowering of goods was always attended with the utmost danger to the men in the wheel; as every one must be sensible of, who has seen such engines at work.

And it is surprising that the masters of wharfs and cranes should be so regardless of the limbs, or even

Note 38. Since the first edition of this book was printed, I have seen the same crane again; and find, that though the working parts are much the same as above described, yet the method of raising or lowering the trundle *B*, and the catch *R*, are better contrived than I had described them.—*Note by Author.*

lives of their workmen, that excepting the late Sir *James Creed* of Greenwich, and some gentlemen at Bristol, there is scarcely an instance of any who has used this safe contrivance.[39]

Wheel-carriages.

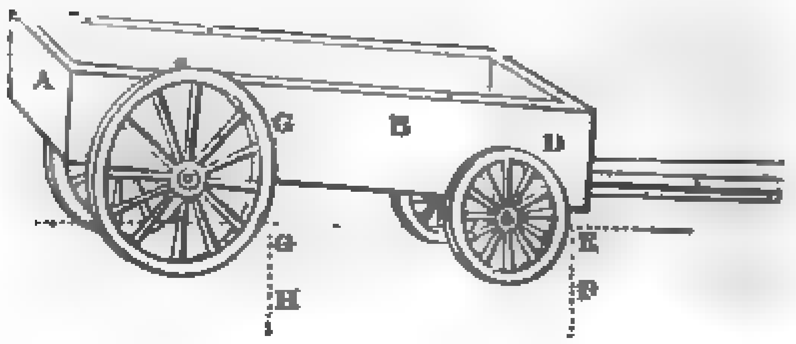
The structure of *wheel-carriages* is generally so well known, that it would be needless to describe them. And therefore, we shall only point out some inconveniences attending the common method of placing the wheels, and loading the wagons.

In coaches, and all other four-wheeled carriages, the fore-wheels are made of a less size than the hind ones, both on account of turning short, and to avoid cutting the braces: otherwise the carriage would go much easier if the fore-wheels were as high as the hind ones, and the higher the better, because they would sink to less depths in little hollowings in the roads, and be the more easily drawn out of them. But carriers and coachmen give another reason for making the fore-wheels much lower than the hind-wheels; namely, that when they are so, the hind-wheels help to push on the fore ones: which is too unphilosophical and absurd to deserve a refutation, and yet for their satisfaction we shall shew by experiment that it has no existence but in their own imaginations.

It is plain that the small wheels must turn as much oftener round than the great ones, as their circumferences are less. And therefore, when the carriage is loaded equally heavy on both axles, the fore-axle must

Note 39. The cranes described by our author are still very generally employed, although others of a more improved form have, in some cases, been substituted. One of which will be shewn in a subsequent page. An expanding wheel crane has been recommended by the Society of Arts, who have rewarded its ingenious inventor; but when ordinary weights are to be raised, the labourers to whom these engines are generally entrusted, appear to prefer the more obvious arrangement of wheels and pinions, by means of which the same mechanical advantage is attained.

LECT. IV. sustain as much more friction, and consequently wear out as much sooner, than the hind-axle, as the fore-wheels are less than the hind ones. But the great misfortune is, that all the carriers to a man do obstinately persist, against the clearest reason and demonstration, in putting the heavier part of the load upon the fore-axle of the wagon; which not only makes the friction greatest where it ought to be least, but also presseth the fore-wheels deeper into the ground than the hind-wheels, notwithstanding the fore-wheels, being less than the hind-ones, are with so much the greater difficulty drawn out of a hole or over an obstacle, even supposing the weights on their axles were equal. For the difficulty, with equal weights, will be as the depth of the hole or height of the obstacle is to the semi-diameter of the wheel. Thus, if we suppose the small wheel *D* of the wagon *A B* to fall



into a hole of the depth *E F*, which is equal to the semi-diameter of the wheel, and the wagon to be drawn horizontally along; and it is evident that the point *E* of the small wheel will be drawn directly against the top of the hole; and therefore, all the power of horses and men will not be able to draw it out, unless the ground gives way before it. Whereas, if the hind-wheel *C* falls into such a hole, it sinks not near so deep in proportion to its semi-diameter; and therefore, the point *G* of the large wheel will not be drawn directly, but obliquely, against the top of the hole; and so will be easily got out of it. Add to this, that as a small wheel will often sink to the bottom of a hole, in which a great wheel will go but a

very little way, the small wheels ought in all reason to be loaded with less weight than the great ones: and then the heavier part of the load would be less jolted upward and downward, and the horses tired so much the less, as their draught raised the load to less heights.

It is true, that when the wagon-road is much up-hill, there may be danger in loading the hind part much heavier than the fore part; for then the weight would overhang the hind-axle, especially if the load be high, and endanger tilting up the fore-wheels from the ground In this case, the safest way would be to load it equally heavy on both axles; and then, as much more of the weight would be thrown upon the hind-axle than upon the fore one, as the ground rises from a level below the carriage. But as this seldom happens, and when it does, a small temporary weight laid upon the pole between the horses would overbalance the danger; and this weight might be thrown into the wagon when it comes to level ground; it is strange that an advantage so plain and obvious as would arise from loading the hind-wheels heaviest, should not be laid hold of, by complying with this methed.

To confirm these reasonings by experiment: let a small model of a wagon be made, with its fore-wheels 2¼ inches in diameter, and its hind-wheels 4½; the whole model weighing about 20 ounces. Let this little carriage be loaded any how with weights, and have a small cord tied to each of its ends, equally high from the ground it rests upon; and let it be drawn along a horizontal board, first by a weight in a scale hung to the cord at the fore-part; the cord going over a pulley at the end of the board to facilitate the draught, and the weight just sufficient to draw it along. Then, turn the carriage, and hang the scale and weight to the hind cord, and it will be found to move along with the same velocity as at first: which shews, that the power required to draw the carriage is all the same, whether the

LECT. IV. great or small wheels are foremost; and therefore the great wheels do not help in the least to push on the small wheels in the road.

Hang the scale to the fore-cord, and place the fore-wheels (which are the small ones) in two holes, cut three eighth parts of an inch deep into the board; then put a weight of 32 ounces into the carriage, over the fore-axle, and an equal weight over the hind one: this done, put 44 ounces into the scale, which will be just sufficient to draw out the fore-wheels: but if this weight be taken out of the scale, and one of 16 ounces be put into its place, if the hind-wheels are placed in the holes, the 16 ounce weight will draw them out; which is little more than a third part of what was necessary to draw out the fore-wheels. This shews, that the larger the wheels are, the less power will draw the carriage, especially on rough ground.

Put 64 ounces over the axle of the hind-wheels, and 32 over the axle of the fore ones, in the carriage; and place the fore-wheels in the holes: then put 38 ounces into the scale, which will just draw out the fore-wheels; and when the hind ones come to the hole, they will find but very little resistance, because they sink but a little way into it.

But shift the weights in the carriage, by putting the 32 ounces upon the hind-axle, and the 64 ounces upon the fore one; and place the fore-wheels in the holes: then, if 76 ounces be put into the scale, it will be found no more than sufficient to draw out these wheels; which is double the power required to draw them out, when the lighter part of the load was put upon them: which is a plain demonstration of the absurdity of putting the heaviest part of the load in the fore-part of the wagon.

Every one knows what an outcry was made by the generality, if not the whole body, of the carriers, against the broad-wheel act; and how hard it was to persuade them to comply with it, even though the government

allowed them to draw with more horses, and carry greater loads, than usual. Their principal objection was, that as a broad wheel must touch the ground in a great many more points than a narrow wheel, the friction must of course be just so much the greater; and consequently, there must be so many more horses than usual, to draw the wagon. I believe that the majority of people were of the same opinion, not considering, that if the whole weight of the wagon and load in it bears upon a great many points, each sustains a proportionably less degree of weight and friction, than when it bears only upon a few points; so that what is wanting in one, is made up in the other; and therefore will be just equal under equal degrees of weight, as may be shewn by the following plain and easy experiment.

Let one end of a piece of packthread be fastened to a brick, and the other end to a common scale for holding weights: then, having laid the brick edgewise on a table, and let the scale hang under the edge of the table, put as much weight into the scale as will just draw the brick along the table. Then, taking back the brick to its former place, lay it flat on the table, and leave it to be acted upon by the same weight in the scale as before, which will draw it along with the same ease as when it lay upon its edge. In the former case, the brick may be considered as a narrow wheel on the ground; and in the latter as a broad wheel. And since the brick is drawn along with equal ease, whether its broad side or narrow edge touches the table, it shews that a broad wheel might be drawn along the ground with the same ease as a narrow one (supposing them equally heavy) even though they should drag, and not roll, as they go along.

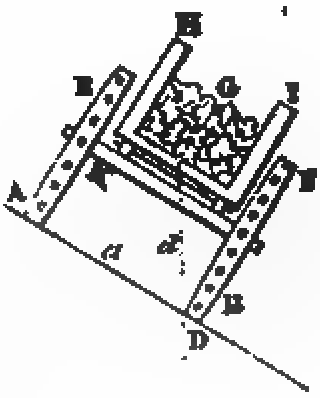
As narrow wheels are always sinking into the ground, especially when the heaviest part of the load lies upon them, they must be considered as going constantly up

LECT. IV. hill, even on level ground. And their sides must sustain a great deal of friction by rubbing against the ruts made by them. But both these inconveniences are avoided by broad wheels; which, instead of cutting and ploughing up the roads, roll them smooth, and harden them; as experience testifies in places where they have been used, especially either on wettish or sandy ground: though, after all, it must be confessed that they will not do in stiff clayey cross roads; because they would soon gather up as much clay as would be almost equal to the weight of an ordinary load.

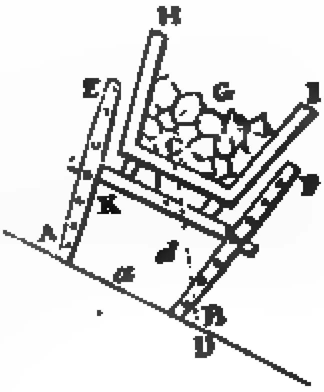
If the wheels were always to go upon smooth and level ground, the best way would be to make the spokes perpendicular to the naves; that is, to stand at right angles to the axles; because they would then bear the weight of the load perpendicularly, which is the strongest way for wood. But because the ground is generally uneven, one wheel often falls into a cavity or rut when the other does not; and then it bears much more of the weight than the other does: in which case, concave or dishing wheels are best, because, when one falls into a rut, and the other keeps upon high ground, the spokes become perpendicular in the rut, and therefore have the greatest strength when the obliquity of the load throws most of its weight upon them; whilst those on the high ground have less weight to bear, and therefore need not be at their full strength. So that the usual way of making the wheels concave is by much the best.

The axles of the wheels ought to be perfectly straight, that the rims of the wheels may be parallel to each other; for then they will move easiest, because they will be at liberty to go on straight forwards. But, in the usual way of practice, the axles are bent downward at their ends; which brings the sides of the wheels next the ground nearer to one another than their opposite or higher sides are: and this not only makes the wheels to drag sideways as they go along, and give the load a

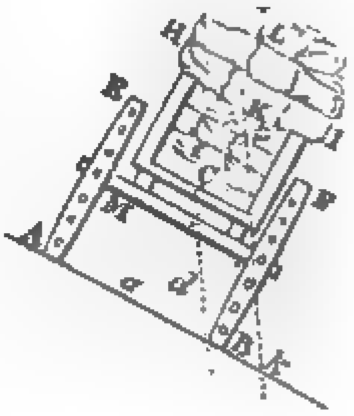
much greater power of crushing them than when they are parallel to each other, but also endangers the overturning of the carriage when any wheel falls into a hole or rut; or when the carriage goes in a road which has one side lower than the other, as along the side of a hill. Thus (in the hind view of a wagon or cart) let *A E* and *B F* be the great wheels parallel to each other, on their straight axle *K*, and *H C I* the carriage loaded with heavy goods from *C* to *G*. Then as the carriage goes on in the oblique road *A a B*, the center of gravity of the whole machine and load will be at *C*;* and the line of direction *C d D* falling within the wheel *B F*, the carriage will not overset.



But if the wheels be inclined to each other on the ground, as *A E* and *B F* are, and the machine be loaded as before, from *C* to *G*, the line of direction *C d D* falls without the wheel *B F*, and the whole machine tumbles over. When it is loaded with heavy goods (such as lead or iron) which lie low, it may travel upon an oblique road so long as the center of gravity is at *C*, and the line of direction *C d* (as in the preceding figure) falls within the wheels



but if it be loaded high with lighter goods (such as wool-packs from *C* to *L*, the center of gravity is raised from *C* to *K*, which throws the line of direction *K k* without the lowest edge of the wheel *B F*, and then the load oversets the wagon.



Note 40.—See Page 5

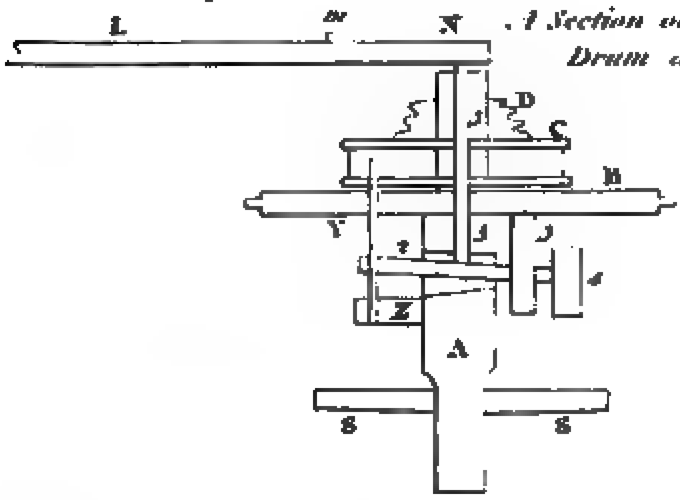
LECT. IV. If there be some advantage from small fore-wheels, on account of the carriage turning more easily and short than it can be made to do when they are large; there is at least as great a disadvantage attending them, which is, that as their axle is below the level of the horses' breasts, the horses not only have the loaded carriage to draw along, but also part of its weight to bear; which tires them sooner, and makes them grow much stiffer in their hams, than they would be if they drew on a level with the fore axle. And for this reason, we find coach horses soon become unfit for riding. So that on all accounts it is plain, that the fore-wheels of all carriages ought to be so high, as to have their axles even with the breasts of the horses; which would not only give the horses a fair draught, but likewise cause the machine to be drawn by a less degree of power.

We shall conclude this Lecture with a description of Mr. *Vauloue's* curious engine, which was made use of for driving the piles of Westminster-bridge: and the reader may cast his eyes upon the first and second figures of Plate I, in which the same letters of reference are annexed to the same parts, in order to explain those in the second, which are either partly or wholly hid in the first.

The *pile-engine.* *A* is the great upright shaft or axle, on which are the great wheel *B* and drum *C*, turned by horses joined to the bars *S, S*. The wheel *B* turns the trundle *X*, on the top of whose axis is the fly *O*, which serves to regulate the motion, and also to act against the horses, and keep them from falling when the heavy ram *Q* is discharged to drive the pile *P* down into the mud in the bottom of the river. The drum *C* is loose upon the shaft *A*, but is locked to the wheel *B* by the bolt *Y*. On this drum the great rope *H H* is wound; one end of the rope being fixed to the drum, and the other to the follower *G*, to which it is conveyed over the pulleys *I* and *K*. In the follower *G* is contained the tongs *F* (see

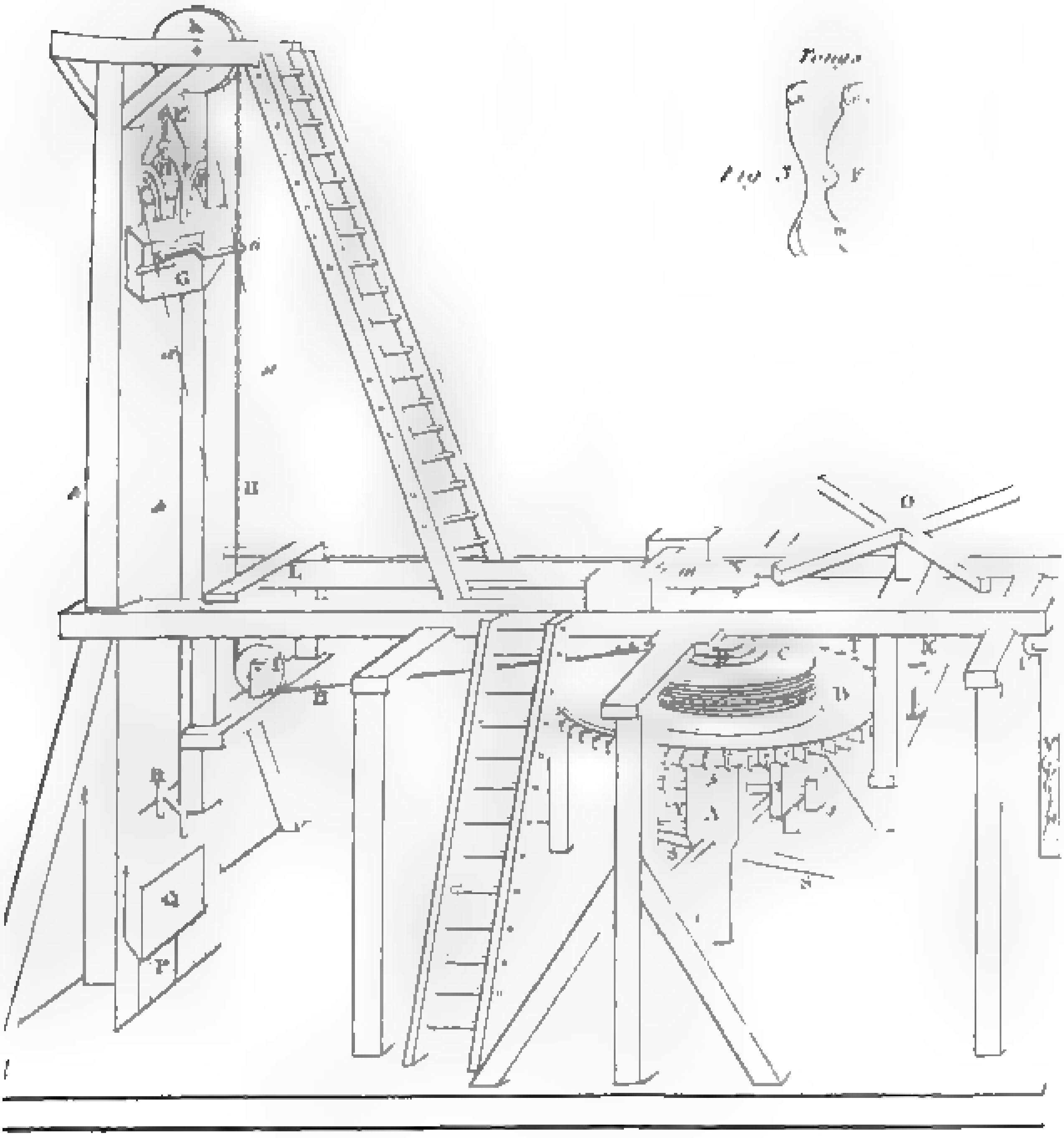
Pile Driving Engine.

Fig. 2.



A Section of the great Wheel Drum and Shaft &c.

Fig. 1.



Tongs

Fig. 3.

Fig. 3.) that takes hold of the ram *Q* by the staple *R* for drawing it up. *D* is a spiral or fusy fixed to the drum, on which is wound the small rope that goes over the pulley *U*, under the pulley *V*, and is fastened to the tope of the frame at 7. To the pulley block *V* is hung the counterpoise *W*, which hinders the follower from accelerating as it goes down to take hold of the ram: for, as the follower tends to acquire velocity in its descent, the line *T* winds downwards upon the fusy, on a larger and larger radius, by which means the counterpoise *W* acts stronger and stronger against it; and so allows it to come down with only a moderate and uniform velocity. The bolt *Y* locks the drum to the great wheel, being pushed upward by the small lever 2, which goes through a mortise in the shaft *A*, turns upon a pin in the bar 3 fixed to the great wheel *B*, and has a weight 4, which always tends to push up the bolt *Y* through the wheel into the drum. *L* is the great lever turning on the axis *m*, and resting upon the forcing bar 5, 5, which goes down through a hollow in the shaft *A*, and bears up the little lever 2.

By the horses going round, the great rope *H* is wound about the drum *C*, and the ram *Q* is drawn up by the tongs *F* in the follower *G*, until the tongs comes between the inclined planes *E*; which, by shutting the tongs at the top, opens it at the foot, and discharges the ram, which falls down between the guides *b b* upon the pile *P*, and drives it by a few strokes as far into the mud as it can go; after which, the top part is sawed off close to the mud, by an engine for that purpose.[41] Immediately after the ram is discharged, the piece 6 upon the

Note 41. When the piles are driven for the purpose of constructing a coffer-dam, they may be afterwards raised by the hydrostatic press of Bramah. The plan has been successfully adopted in many cases, and its advantage over our author's mode of sawing them beneath the water, will be sufficiently obvious, when we come to a description of that instrument.

LECT. IV. follower *G* takes hold of the ropes *a, a*, which raise the end of the lever *L*, and cause its end *N* to descend and press down the forcing bar 5 upon the little lever 2, which by pulling down the bolt *Y*, unlocks the drum *C* from the great wheel *B*; and then, the follower, being at liberty, comes down by its own weight to the ram; and the lower ends of the tongs slip over the staple *R*, and the weight of their heads causes them to fall outward, and shuts upon it. Then the weight 4 pushes up the bolt *Y* into the drum, which locks it to the great wheel, and so the ram is drawn up as before.

As the follower comes down, it causes the drum to turn backward, and unwinds the rope from it, whilst the horses, great wheel, trundle, and fly, go on with an uninterupted motion: and as the drum is turning backward, the counterpoise *W* is drawn up, and its rope *T* wound upon the spiral fusy *D*.

There are several holes in the under side of the drum, and the bolt *Y* always takes the first one that it finds when the drum stops by the falling of the follower upon the ram; until which stoppage, the bolt has not time to slip into any of the holes.

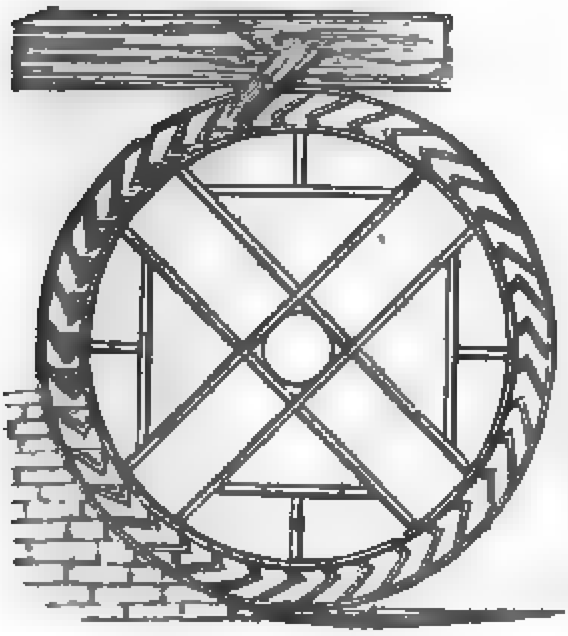
This engine was placed upon a barge on the water, and so was easily conveyed to any place desired.—I never had the good fortune to see it, but drew this figure from a model which I made from a print of it; being not quite satisfied with the view which the print gives. I have been told that the ram was a ton weight, and that the guides *b b*, between which it was drawn up and let fall down, were 30 feet high. I suppose the great wheel might have had 100 cogs, and the trundle ten staves or rounds; so that the fly would make ten revolutions for one of the great wheel.[a]

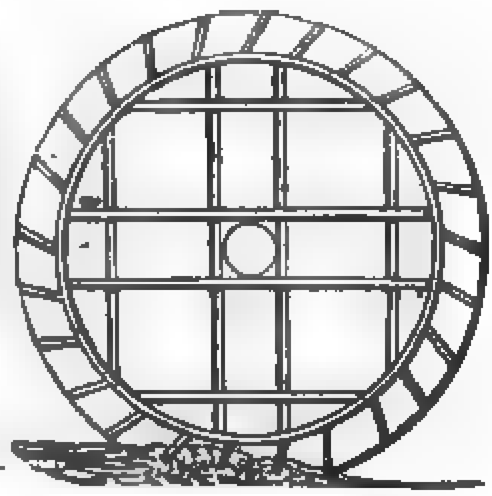
Note 42. Engines of this description, although much simplified, are now very generally employed; not merely in the construction of bridges and other branches of hydraulic architecture, but also in the manufacture of buttons, and other purposes connected with the arts.

The operation of the pile engine may be best understood by reference to a former note in which the doctrine of accelerated motion is examined, and it may be only necessary to add, that the momentum thus acquired is exactly equivalent to so much additional weight falling upon the head of the pile. LECT IV.

Note 43. The following additional illustration of the preceding subjects will be found valuable to the practical artisan, and they have been introduced at the close of the Lecture to prevent an unnecessary interference with our Author's text.

There are four principal modes of employing the force of water as a prime mover in machinery, and of these the under and over-shot water-wheels, are the most important: of the other two, namely, the breast-wheel and Barker's mill, but little need be said, as the latter is but seldom resorted to, and the breast wheel may be considered but as a modification of the two preceding. The following diagrams will best illustrate the under and over-shot water-wheels.





The over-shot wheel it will be seen owes its power to the weight of the water, while the under-shot, on the contrary, depends on its impulse.

In order to determine the effect of any force employed in machinery, we must consider not only its magnitude, but also the velocity with which it can be brought into action, and we must estimate the ultimate value of the power, by the joint ratio, or the product, of the force and the velocity. Thus, if we had a corn-mill, for example, in which we wished the mill-stone to re-

LECT. IV. volve with a certain velocity, and to overcome a given resistance, and supposing that this effect could be obtained by means of a certain train of wheels from a given source of motion; if the velocity of the motion at its source be reduced to one half, we must double the diameter of one of the wheels by which the force is communicated, in order togive the mill-stone the desired velocity; and thus we must introdnce a mechanical disadvantage, which can only be compensated by a double intensity in the force at its origin.

If we apply this estimation of effect to the motion of an overshot wheel, we shall find that the velocity of the wheel, and consequently its breadth, and the magnitude of its buckets, is perfectly indifferent with respect to the value of its operation: for, supposing the stream to enter the buckets with the uniform velocity of the wheel, the quantity of water in the wheel at any one time, and consequently the pressure, must be inversely as the velocity, so that the product of the force into the velocity will be the same, however they may separately vary. If, however, the velocity were to become very considerable, it would be necessary to sacrifice a material part of the fall in order that the water might acquire this velocity before its arival at the wheel; but a fall of one foot or even less, is sufficient for producing any velocity that would be practically convenient: and it is obvious, on the other hand, that a certain velocity may be procured from a wheel moving rapidly, with less machinery than from another which moves more slowly. In general, the velocity of the surface of the wheel is between two and six feet in a second; and whether it be greater or smaller, the force actually applied will always be equal in effect to the weight of a portion of the stream employed, equal in length to the height of the wheel. In order to avoid the resistance which might be occasioned by the stagnant water below the wheel, it is a good practice to turn the stream backwards upon its nearer half, so that the water, when discharged, may run off in the general direction of its motion.

If we suffer the stream of water to acquire the utmost velocity that the whole fall can produce, and to strike horizontally against the float-boards of an under-shot wheel, or if we wish to employ the force of a river running in a direction nearly horizontal, the wheel must move, in order to produce the greatest effect, with half the velocity of the stream. For the whole quantity of water impelling the float-boards is nearly the same, whatever may be the velocity, especially if the wheel is properly inclosed in a narrow channel, and hence it is easy to calculate that the greatest possible effect will be produced when the relative velocity of

stream, striking the float-boards, is equal to the velocity of wheel itself. The pressure on the float-boards is equal to of a stream containing the same quantity of water, and ing a fixed obstacle with half the velocity, that is, such a am as escapes from the wheel, which must be twice as deep vice as wide as the original stream, since its motion is only half as rapid; and a column of such a stream, of twice the ht due to its velocity, that is, of half the height of the fall, g as we have already seen, the measure of the hydraulic pres-, this force will be precisely half as great as that of a similar mn, acting on an over-shot wheel, which moves with the same city. But the stream thus retarded will not retain the other of its mechanical power; since its greatest effect will be in same proportion to that of an equal stream acting on an over-wheel with one fourth of the fall of the former; and the re-ing fourth of the power is lost in producing the change of of the water and in overcoming its friction. In whatever we apply the force of water, we shall find that the mechanical r which it posesses must be measured by the product of the tity multiplied by the height from which it descends: for ex-le, a hogshead of water capable of descending from a height n feet, possesses the same power as ten hogsheads descend-rom a height of one foot; and a cistern filled to the height of eet above its orifice possesses 100 times as much power as the cistern filled to the height of one foot only.

LECT. IV

hen, therefore, the fall is sufficiently great, an over-shot l is far preferable to an under-shot wheel, and where the s too small for an over-shot wheel, it is most advisable to oy a breast-wheel, which partakes of its properties; its boards consisting of two portions meeting at an angle, so as proach to the nature of buckets, and the water being also me measure confined within them by the assistance of a p or arched channel which follows the curve of the wheel, out coming too nearly into contact with it, so as to produce cessary friction. When the circumstances do not admit of a breast-wheel, we must be contented with an under-shot l: it is recommended, for such a wheel, that the float-boards placed as to be perpendicular to the surface of the water at time that they rise out of it: that only one half of each ld ever be below the surface, and that from three to five ld be immersed at once, according to the magnitude of the l. Sometimes, however, it has been thought eligible to loy a much smaller number: thus the water-wheel which

LECT IV. propels Mr. Symington's steam-boat has only six float-boards i its whole circumference.

Since the water escaping from an under-shot wheel still retains a part of its velocity, it is obvious that this may be employed for turning a second wheel, if it be desirable to preserve as much as possible of the force. In this case, by causing the first wheel to move with two thirds of the velocity of the stream, the whole effect of both will be one third greater than that of a single wheel placed in the same stream; but it must be considered that the expense of the machinery will also be materially increased.—*Vide* DR. YOUNG.

The following comparative view of the effects of wind, water, and animal force, when applied as prime movers in machinery, is extracted from the Editor's treatise on Steam Engines.

From the most accurate observations, it appears, that the physical powers of the human race differ very widely, not only in various individuals, but also in different climates; the value of a man, therefore, as a working machine, will not be so great beneath the torrid zone as in the more temperate climate of Europe. This will serve to illustrate the great advantage which our Colonists, particularly in the West Indies, would derive from the more general employment of inanimate force; the day-labour of a negro in the sugar countries amounting to little more than one-third of that performed by a European mechanic.

A labourer, working ten hours a day, can raise in one minute a weight equivalent to 3750 pounds one foot high, or about sixty cubic feet of water in the same time: while the power of a horse, working eight hours per day, may be correctly averaged at 20,000 pounds. Smeaton states, that this animal, by means of pumps, can raise two hundred and fifty hogsheads of water ten feet high in an hour. It is a well-known fact, also, that men, when trained to running, are able, on the average of several days being taken, to outstrip the fleetest horse: and yet it will be seen from the above statement, that his force, if properly applied, is at least six times that of the most powerful man.

The use of water, as an impelling power, both for the turning of machinery and other purposes connected with the useful arts, appears to have been known at a very early period. Vitruvius describes a variety of machines for this purpose, the earliest of which were employed merely to raise a portion of the fluid by which they were impelled. The most simple method of applying this element as a mechanical agent, evidently consisted in the construction of a wheel, the periphery of which was composed of a

number of float-boards. This, on being exposed to the action of a running stream, was afterwards employed to give motion to a variety of mills, and is at the present time employed in almost every species of machinery.

Among the most celebrated hydraulic machines, we may enumerate the machine of Marly. This, when first constructed, appears to have produced one-eighth of the power expended, so that seven-eighths of its power were usually lost. This misapplied power has been injurious to the engine; and the wear it has occasioned, has reduced the mechanical effect very materially. But this may be considered as an extreme case, and we select it merely as an instance of that total ignorance of the first principles of mechanics, which characterized some foreign engineers of the last century.

It may, however, be advisable to examine the ratio of power expended in comparison with that of the effect produced in some of the most simple hydraulic machines; and by this calculation, the amount of friction, &c. may be accurately ascertained.

	Power		*Effect*
Under-shot water-wheel	9	=	3
Over-shot do	10	=	8
Hydraulic Ram. (This machine will make from 20 to 100 strokes per minute.)	10	=	6
Large machine at Chremnitz, (each stroke occupying about three minutes.)	9	=	3

But the water-mill, which is the usual machine employed, even in its most improved form, is far from being beneficial either to the agriculturist or the manufacturer. The former is injured by the laws which prohibit the draining of mill-streams for the purposes of irrigation, by which much improvement is kept back that would otherwise take place; while the health of the latter, in the immediate neighbourhood of manufacturing districts, is much injured by the stagnant condition of the water which is thus unnecessarily dammed up.

Wind, which we may consider as the next substitute for animal power, appears to have been first employed to give motion to machinery in the beginning of the sixth century. The use of this species of mechanic force, is however principally limited to the grinding of corn, the pressing of seed, and other simple manipulations; the great irregularity of this element precluding its application to those processes which require a continued motion.

A wind-mill with four sails, measuring seventy feet from the

LECT. IV.

extremity of one sail, to that of the opposite one, each being six feet and a half in width, is capable of raising 926 pounds, two hundred and thirty-two feet in a minute; and of working on an average eight hours per day. This is equivalent to the work of thirty-four men: twenty-five square feet of canvas performing the average work of a day-labourer. A mill of this magnitude seldom requires the attention of more than two men; and it will thus be seen, that making allowance for its irregularity, wind possesses a decided superiority over every species of animal labour.——The advantages arising from the use of steam as a prime mover in machinery will be examined in a subsequent page

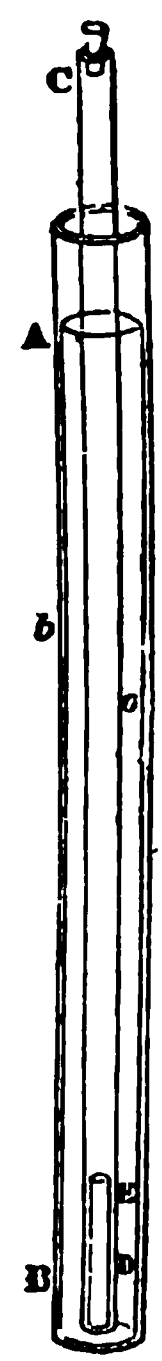
LECT. V.

LECTURE V.

OF HYDROSTATICS, AND HYDRAULIC MACHINES, IN GENERAL.

The science of *hydrostatics* treats of the nature, gravity, pressure, and motion of fluids in general; and of weighing solids in them.

A fluid is a body that yields to the least pressure or difference of pressures. Its particles are so small, that they cannot be discerned by the best microscopes; they are hard, since no fluid except air or steam, can be pressed into a less space than it naturally possesses;[44] and they must be round and smooth, seeing they are so easily moved among one another. Definition of a fluid



All bodies, both fluid and solid, press downwards by the force of gravity: but fluids have this wonderful property, that their pressure upwards and sidewise is equal to their pressure downwards; and this is always in proportion to their perpendicular height, without any regard to their quantity; for, as each particle is quite free to move, it will move towards that part or side on which the pressure is least. And hence no particle or quantity of a fluid can be at rest, till it is every way equally pressed.

Fluids press as much upward as downward.

To shew by experiment that fluids press upward as well as downward, let *A B* be a long upright tube filled with water near to its top; and *C D* a small tube open at both ends, and immersed into the water in the large one: if the immersion be quick, you will see the water rise in the small tube to the same height that it stands in the great one, or until the sur-

Note 44. Subsequent experiments have proved that water is compressible, and a variety of interesting facts connected with this subject, will be inserted at the close of the Lecture.

LECT V. faces of the water in both are on the same level: which shews that the water is pressed upward into the small tube by the weight of what is in the great one; otherwise it could never rise therein, contrary to its natural gravity; unless the diameter of the bore were so small, that the attraction of the tube would raise the water; which will never happen, if the tube be as wide as that in a common barometer. And, as the water rises no higher in the small tube than till its surface be on a level with the surface of the water in the great one, this shews that the pressure is not in proportion to the quantity of water in the great tube, but in proportion to its perpendicular height therein: for there is much more water in the great tube all round the small one, than what is raised to the same height in the small one, as it stands in the great.

Take out the small tube, and let the water run out of it; then it will be filled with air. Stop its upper end with the cork *C*, and it will be full of air all below the cork: this done, plunge it again to the bottom of the water in the great tube, and you will see the water rise up into the height *E*; which shews that the air is a body, otherwise it could not hinder the water from rising up to the same height as it did before, namely, to *A*; and in so doing, it drove the air out at the top; but now the air is confined by the cork *C*: and it also shews that the air is a compressible body, for if it were not so, a drop of water could not enter into the tube.

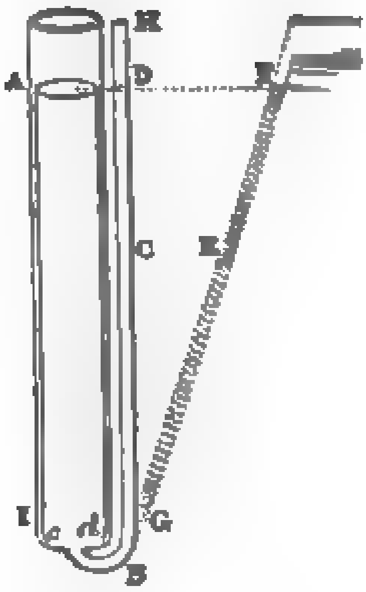
The pressure of fluids being equal in all directions, it follows that the sides of a vessel are as much pressed by a fluid in it, all around, in any given ring of points, as the fluid below that ring is pressed by the weight of all that stands above it. Hence the pressure upon every point in the sides, immediately above the bottom, is equal to the pressure upon every point of the bottom. To shew this by experiment, let a hole be made at

e in the side of the tube *A B*, close by the bottom; and another hole of the same size in the bottom at *C*; then pour water into the tube, keeping it full as long as you choose the holes should run, and have two basons ready to receive the water that runs through the two holes, until you think there is enough in each bason; and you will find, by measuring the quantities, that they are equal; which shews that the water ran with equal speed through both holes: which it could not have done, if it had not been equally pressed through them both. For, if a hole of the same size be made in the side of the tube, as about *f*, and if all three are permitted to run together, you will find that the quantity run through the hole at *f* is much less than what has run in the same time through either of the holes *C* or *e*. LECT. V.

In the same figure, let the tube be turned up from the bottom at *C* into the shape *D E*, and the hole at *C* be stopped with a cork. Then, pour water into the tube to any height, as *A g*, and it will spout up in a jet *EFG*, nearly as high as it is kept in the tube *A B*, by continuing to pour in as much there as runs through the hole *E*; which will be the case whilst the surface *A g* keeps at the same height. And if a little ball of cork *G* be laid upon the top of the jet, it will be supported thereby, and dance upon it. The reason why the jet rises not quite so high as the surface of the water *A g*, is owing to the resistance it meets with in the open air: for, if a tube, either great or small, was screwed upon the pipe at *E*, the water would rise in it until the surfaces of the water in both tubes were on the same level; as will be shewn by the next experiment.

Any quantity of a fluid, how small soever, may be made to balance and support any quantity, how great soever. This is deservedly termed *the hydrostatical* The *hydrostatic paradox.*

LECT. V. *paradox*, which we shall first shew by an experiment, and then account for it upon the principle above-mentioned, namely, that *the pressure of fluids is directly as their perpendicular height, without any regard to their quantity.*



Let a small glass tube DCG, open throughout, and bended at B, be joined to the end of a great one AI at cd, where the great one is also open; so that these tubes in their openings may freely communicate with each other. Then pour water through a small necked funnel into the small tube at H; this water will run through the joining of the tubes at cd, and rise up into the great tube; and if you continue pouring until the surface of the water comes to any part, as A in the great tube, and then leave off, you will see that the surface of the water in the small tube will be just as high, at D; so that the perpendicular height of the water will be the same in both tubes, however small the one be in proportion to the other. This shews, that the small column DCG balances and supports the great column Acd; which it could not do if their pressures were not equal against one another in the recurved bottom at B.—If the small tube be made longer, and inclined in the situation GEF, the surface of the water in it will stand at F, on the same level with the surface A in the great tube; that is, the water will have the same perpendicular height in both tubes, although the column in the small tube is longer than that in the great one; the former being oblique, and the latter perpendicular.

Since, then, the pressure of fluids is directly as their perpendicular heights, without any regard to their quantities, it appears that whatever the figure or size of the

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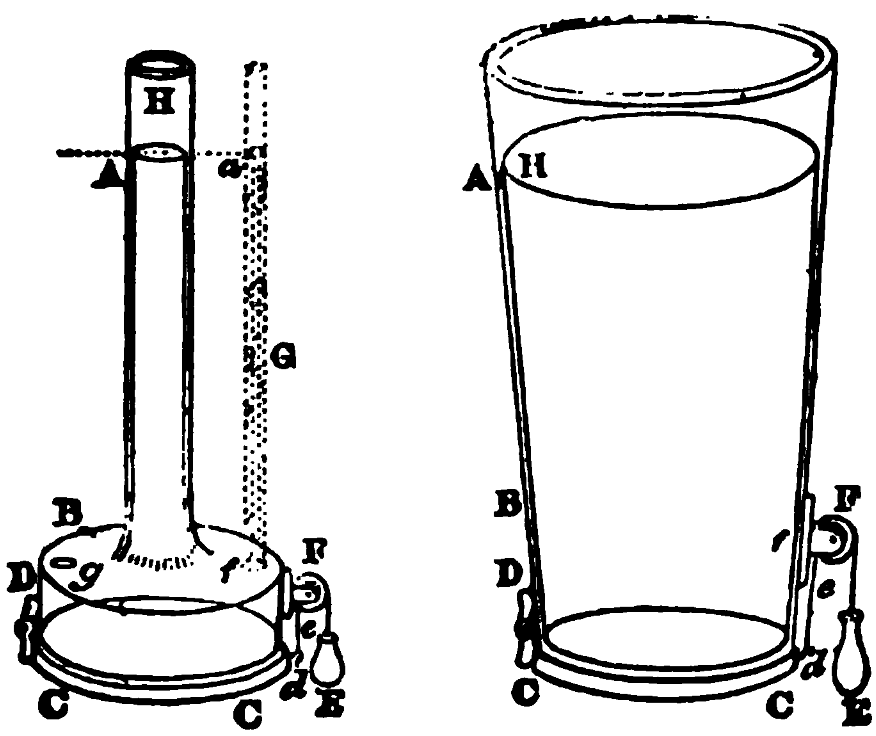
vessels be, if they are of equal heights, and if the areas of their bottoms are equal, the pressures of equal heights of water are equal upon the bottoms of these vessels; even though the one should hold a thousand, or ten thousand times as much water as would fill the other. To confirm this part of the hydrostatical paradox by an experiment, let two vessels be prepared of equal heights, but very unequal contents, such as *A B*, *A B*. Let each vessel be open at both ends, and



their bottoms *D d*, *D d*, be of equal widths. Let a brass bottom *C C* be exactly fitted to each vessel; not to go into it, but for it to stand upon; and let a piece of wet leather be put between each vessel and its brass bottom, for the sake of closeness. Join each bottom to its vessel by a hinge *D*, so that it may open like the lid of a box; and let each bottom be kept up to its vessel by equal weights *E* and *E*, hung to lines which go over the pulleys *F* and *F*, (whose blocks are fixed to the sides of the vessels at *f*) and the lines tied to hooks at *d* and *d*, fixed in the brass bottoms opposite to the hinges *D* and *D*. Things being thus prepared and fitted, hold the vessel *A B* (the second figure) upright in your hands over a bason on a table, and cause water to be poured into the vessel slowly, till the pressure of the water bears down its bottom at the side *d*, and raises

LECT. V. the weight *E*; and then part of the water will run out at *d*. Mark the height at which the surface *H* of the water stood in the vessel, when the bottom began to give way at *d*; and then, holding up the other vessel *A B* (the first figure in the preceding page) in the same manner, cause water to be poured into it at *H*; and you will see that when the water rises to *A* in this vessel, just as high as it did in the former, its bottom will also give way at *d*, and it will lose part of the water.

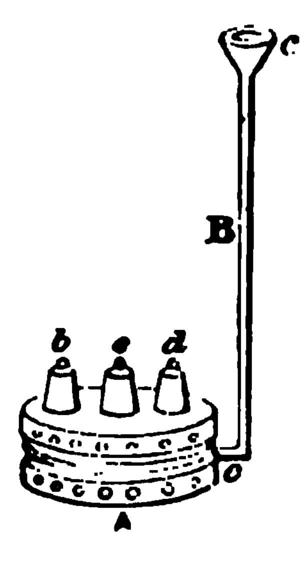
The natural reason of this surprising phenomenon is, that since all parts of a fluid at equal depths below the surface are equally pressed in all manner of directions, the water immediately below the fixed part *Bf* (in the first figure) will be pressed as much upward against its lower surface within the vessel, by the action of the column *A g*, as it would be by a column of the same height, and of any diameter whatever; (as was evident by the experiment with the tube, p. 113.) and therefore, since action and reaction are equal and contrary to each other, the water immediately below the surface *Bf* will be pressed as much downward by it, as if it was immediately touched and pressed by a column of the height *g A*, and of the diameter *Bf*: and therefore, the water in the cavity *B D d f* will be pressed as much downward upon its bottom *C C*, as the bottom of the other vessel (the second figure) is pressed by all the water above it.

To illustrate this a little farther, let a hole be made at *f* in the fixed top *Bf* (as in the first figure of the preceding page) and let a tube *G* be put into it; then, if water be poured into the tube *A*, it will (after filling the cavity *B d*) rise up into the tube *G*, until it comes to a level with that in the tube *A*; which is manifestly owing to the pressure of the water in the tube *A*, upon that in the cavity of the vessel below it. Consequently that part of the top *Bf*, in which the hole is now made, would, if corked up, be pressed upward with a force

LECT V

equal to the weight of all the water which is supported in the tube G: and the same thing would hold at g. if a hole were made there. And so if the whole cover or top Bf were full of holes, and had tubes as high as the middle one $A g$ put into them, the water in each tube would rise to the same height as it is kept in the tube A, by pouring more into it, to make up the deficiency that it sustains by supplying the others, until they are all full: and then the water in the tube A would support equal heights of water in all the rest of the tubes. Or, if all the tubes except A, or any other one, were taken away, and a large tube equal in diameter to the whole top Bf were placed upon it, and cemented to it, and then if water were poured into the tube that was left in either of the holes, it would ascend through all the rest of the holes, until it filled the large tube to the same height that it stands in the small one, after a sufficient quantity had been poured into it: which shews, that the top Bf was pressed upward by the water under it, and before any hole was made in it, with a force equal to that wherewith it is now pressed downward by the weight of all the water above it in the great tube. And therefore, the reaction of the fixed top Bf must be as great in pressing the water downward upon the bottom CC, as the whole pressure of the water in the great tube would have been, if the top had been taken away, and the water in that tube left to press directly upon the water in the cavity $B D d f$.

The *hydrostatic bellows.*



Perhaps the best machine in the world for demonstrating the upward pressure of fluids, is the hydrostatic bellows A; which consists of two thick oval boards, each about 16 inches broad, and 18 inches long, covered with leather, to open and shut like a common bellows, but without valves; only a pipe B, about three feet high, is fixed into the bellows at e. Let

LECT. V. some water be poured into the pipe at *c*, which will run into the bellows, and separate the boards a little. Then lay three weights *b*, *c*, *d*, each weighing 100 pounds, upon the upper board; and pour more water into the pipe *B*, which will run into the bellows, and raise up the board with all the weights upon it; and if the pipe be kept full, until the weights are raised as high as the leather which covers the bellows will allow them, the water will remain in the pipe, and support all the weights, even though it should weigh no more than a quarter of a pound, and they 300 pounds: nor will all their force be able to cause them to descend and force the water out at the top of the pipe.

The reason of this will be made evident by considering what has been already said of the result of the pressure of fluids of equal heights, without any regard to their quantities. For, if a hole be made in the upper board, and a tube be put into it, the water will rise in the tube to the same height that it does in the pipe; and would rise as high (by supplying the pipe) in as many tubes as the board could contain holes. Now, suppose only one hole to be made in any part of the board, of an equal diameter with the bore of the pipe *B*: and that the pipe holds just a quarter of a pound of water; if a person claps his finger upon the hole, and the pipe be filled with water, he will find his finger to be pressed upward with a force equal to a quarter of a pound. And as the same pressure is equal upon all equal parts of the board, each part, whose area is equal to the area of the hole, will be pressed upward with a force equal to that of a quarter of a pound: the sum of all which pressures against the under side of an oval board 16 inches broad, and 18 inches long, will amount to 300 pounds; and therefore so much weight will be raised up and supported by a quarter of a pound of water in the pipe.

Hence, if a man stands upon the upper board, and

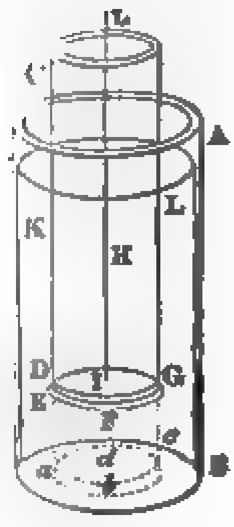
blows into the bellows through the pipe *B*, he will raise himself upward upon the board · and the smaller the bore of the pipe is, the easier he will be able to raise himself. And then, by clapping his finger upon the top of the pipe, he can support himself as long as he pleases; provided the bellows be air-tight, so as not to lose what is blown into it.

LECT. V.

How a man may raise himself upward by his breath.

Upon this principle of the upward pressure of fluids, a piece of lead may be made to swim in water, by immersing it to a proper depth, and keeping the water from getting above it. Let *C D* be a glass tube open throughout, and *E F G* a flat piece of lead, exactly fitted to the lower end of the tube, not to go within it, but for it to stand upon; with a wet leather between the lead and the tube to make close work. Let this leaden bottom be half an inch thick, and held close to the tube by pulling the packthread *I H L* upward at *L* with one hand, whilst the tube is held in the other by the upper end *C*. In this situation, let the tube be immersed in water in the glass vessel *A B*, to the depth of six inches below the surface of the water at *K;* and then, the leaden bottom *E F G* will be plunged to the depth of somewhat more than eleven times its own thickness: holding the tube at that depth, you may let go the thread at *L*; and the lead will not fall from the tube, but will be kept to it by the upward pressure of the water below it, occasioned by the height of the water at *K* above the level of the lead. For as lead is 11.33 times as heavy as its bulk of water, and is in this experiment immersed to a depth somewhat more than 11.33 times its thickness, and no water getting into the tube between it and the lead, the column of water *E a b c G* below the lead is pressed upward against it by the water *KDEGL* all around the tube; which water being a little more

How lead may be made to swim in water.



LECT. V

than 11.33 times as high as the lead is thick, is sufficient to balance and support the lead at the depth *K E* If a little water be poured into the tube upon the lead, it will increase the weight upon the column of water under the lead, and cause the lead to fall from the tube to the bottom of the glass vessel, where it will lie in the situation *b d*. Or, if the tube be raised a little in the water, the lead will fall by its own weight, which will then be too great for the pressure of the water around the tube upon the column of water below it.

How light wood may be made to lie at the bottom of water.

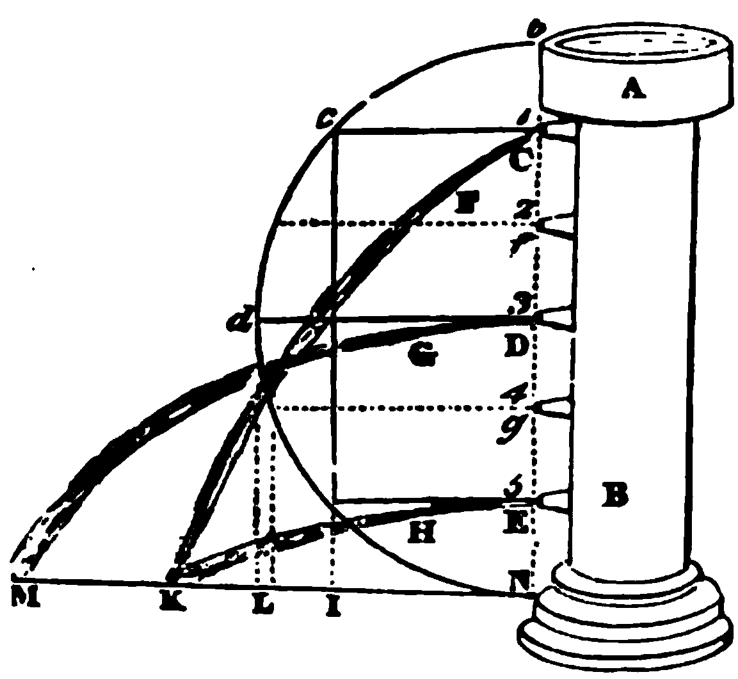
Let two pieces of wood be planed quite flat, so as no water may get in between them when they are put together: let one of the pieces, as *b d*, be cemented to the bottom of the vessel *A B* (p. 121,) and the other piece be laid flat and close upon it, and held down to it by a stick, whilst water is poured into the vessel; then remove the stick, and the upper piece of wood will not rise from the lower one: for, as the upper one is pressed down both by its own weight and the weight of all the water over it, whilst the contrary pressure of the water is kept off by the wood under it, it will lie as still as a stone would do in its place. But if it be raised ever so little at any edge, some water will then get under it; which being acted upon by the water above, will immediately press it upward; and as it is lighter than its bulk of water, it will rise, and float upon the surface of the water.

All fluids weigh just as much in their own element as they do in open air. To prove this by experiment, let as much shot be put into a phial, as, when corked, will make it sink in water: and being thus charged, let it be weighed, first in air, and then in water, and the weights in both cases written down. Then, as the phial hangs suspended in water, and counterpoised, pull out the cork, that water may run into it, and it will descend, and pull down that end of the beam. This done, put as much weight into the opposite scale as will restore the equi

poise; which weight will be found to answer exactly to the additional weight of the phial when it is again weighed in air, with the water in it. LECT. V

The velocity with which water spouts out at a hole in the side or bottom of a vessel, is as the square root* of the depth or distance of the hole below the surface of the water. For, in order to make double the quantity of a fluid run through one hole as through another of the same size, it will require four times the pressure of the other, and therefore must be four times the depth of the other below the surface of the water; and for the same reason, three times the quantity running in an equal time through the same sort of hole, must run with three times the velocity, which will require nine times the pressure; and consequently must be nine times as deep below the surface of the fluid: and so on.—To prove this by an experiment, let two pipes, as *C* and *g*, of equal sized bores, be fixed into the side of the vessel *AB*; the pipe *g* being four times as deep below the surface of the water at *b* in the vessel as the pipe *C* is: and whilst these pipes run, let water be constantly poured into the vessel, to keep the surface still at the same height. Then, if a cup that holds a pint be so placed as to receive the water that spouts from the pipe *C*, and at the same moment a cup that holds a quart be so placed as to receive the water

The velocity of spouting water.



Note 45. The square root of any number is that which being multiplied by itself produces the said number. Thus, 2 is the square root of 4, and 3 is the square root of 9: for 2 multiplied by 2 produces 4; 3 multiplied by 3 produces 9, &c.—*Note* ...

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that spouts from the pipe *g*, both cups will be filled at the same time by their respective pipes.

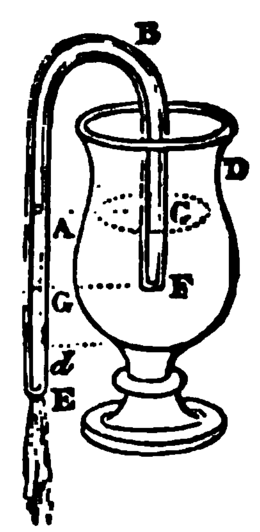
The horizontal distance to which water will spout from pipes.

The horizontal distance, to which a fluid will spout from a horizontal pipe, in any part of the side of an upright vessel below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel, drawn from the mouth of the pipe to a semicircle described upon the altitude of the fluid: and therefore the fluid will spout to the greatest distance possible from a pipe, whose mouth is at the center of the semicircle; because a perpendicular to its diameter (supposed parallel to the side of the vessel) drawn from that point, is the longest that can be possibly drawn from any part of the diameter to the circumference of the semicircle. Thus, if the vessel *A B* be full of water, the horizontal pipe *D* being in the middle of its side, and the semicircle *N d c b* be described upon *D* as a center, with the radius or semidiameter *D g N*, or *D f b*, the perpendicular *D d* to the diameter *N D b* is the longest that can be drawn from any part of the diameter to the circumference *N d c b*. And if the vessel be kept full, the jet *G* will spout from the pipe *D*, to the horizontal distance *N M*, which is double the length of the perpendicular *D d*. If two other pipes, as *C* and *E*, be fixed into the side of the vessel at equal distances above and below the pipe *D*, the perpendiculars *C c*, and *E e*, from these pipes to the semicircle, will be equal; and the jets *F* and *H* spouting from them will each go to the horizontal distance *N K*; which is double the length of either of the equal perpendiculars *C c* or *D d*.

How water may be conveyed over hills and valleys.

Fluids by their pressure may be conveyed over hills and valleys in bended pipes, to any height not greater than the level of the springs from whence they flow. But when they are designed to be raised higher than the springs, forcing engines must be used; which shall be described when we come to treat of pumps.

A *syphon*, generally used for decanting liquor, is a bended pipe, whose legs are of unequal lengths; and the shortest leg must always be put into the liquor intended to be decanted, that the perpendicular altitude of the column of liquor in the other leg may be longer than the column in the immersed leg, especially above the surface of the water. For if both columns were equally high in that respect, the atmosphere, which presses as much upward as downward, and therefore acts as much upward against the column in the leg that hangs without the vessel as it acts downward upon the surface of the liquor in the vessel, would hinder the running of the liquor through the syphon, even though it were brought over the bended part by suction. So that there is nothing left to cause the motion of the liquor, but the superior weight of the column, in the longer leg, on account of its the greater perpendicular height.

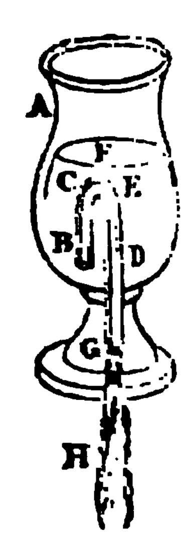


Let *D* be a cup filled with water to *C*, and *A B C* a syphon, whose shorter leg *B C F* is immersed in the water from *C* to *F*. If the end of the other leg were no lower than the line *A C*, which is level with the surface of the water, the syphon would not run, even though the air should be drawn out of it at the mouth *A*. For although the suction would draw some water at first, yet the water would *stop* at the moment the suction ceased; because the air would act as much upward against the water at *A*, as it acted downward for it by pressing on the surface at *C*. But if the leg *A B* comes down to *G*, and the air be drawn out at *G* by suction, the water will immediately follow, and continue to run, until the surface of the water in the cup comes down to *F*; because, till then, the perpendicular height of the column *B A G* will be greater than that of the column *C B*; and consequently, its weight will be greater, until the surface comes down

LECT. V. to *F;* and then the syphon will stop, though the leg *C F* should reach to the bottom of the cup. For which reason, the leg that hangs without the cup is always made long enough to reach below the level of its bottom; as from *d* to *E:* and then, when the syphon is emptied of the air by suction at *E,* the water immediately follows, and by its continuity brings away the whole from the cup; just as pulling one end of a thread will make the whole clue follow.

If the perpendicular height of a syphon, from the surface of the water to its bended top at *B,* be more than thirty-three feet, it will draw no water, even though the other leg were much longer, and the syphon quite emptied of air; because the weight of a column of water thirty-three feet high is equal to the weight of as thick a column of air, reaching from the surface of the earth to the top of the atmosphere; so that there will then be an equilibrium, and consequently, though there would be weight enough of air upon the surface *C* to make the water ascend in the leg *C B* almost to the height *B,* if the syphon were emptied of air, yet the weight would not be sufficient to force the water over the bend; and therefore, it could never be brought over into the leg *B A G.*

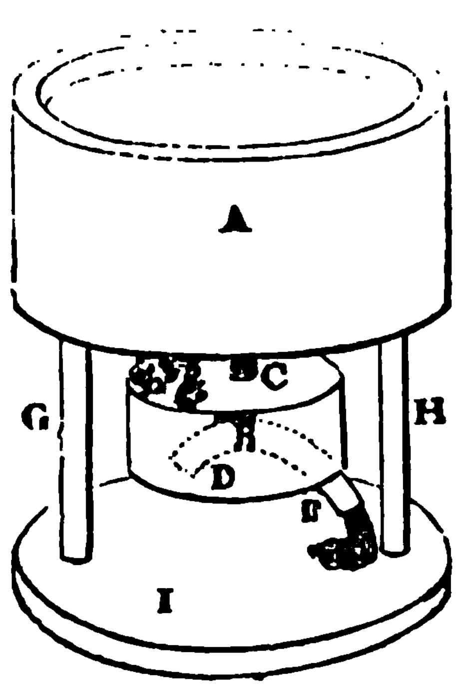
Tantalus's cup. Let a hole be made quite through the bottom of the cup *A,* and the longer leg of the bended syphon *D E B G* be cemented into the hole, so that the end *D* of the shorter leg *D E* may almost touch the bottom of the cup within. Then, if water be poured into this cup, it will rise in the shorter leg by its upward pressure, driving out the air all the way before it through the longer leg: and when the cup is filled above the bend of the syphon at *F,* the pressure of the water in the cup will force it over the bend of the syphon; and it will de-



scend in the longer leg *C B G*, and run through the bottom, until the cup be emptied.

This is generally called *Tantalus's cup*, and the legs of the syphon in it are almost close together; and a little hollow statue, or figure of a man, is sometimes put over the syphon to conceal it; the bend *E* being within the neck of the figure as high as the chin. So that poor *Tantalas* stands up to the chin in water, imagining it will rise a little higher, and he may drink; but instead of that, when the water comes up to his chin, it immediately begins to descend, and so, as he cannot stoop to follow it, he is left as much pained with thirst as ever.

The fountain at command.



The device called *the fountain at command* acts upon the same principle with the syphon in the cup. Let two vessels *A* and *B* be joined together by the pipe *C* which opens into them both. Let *A* be open at top, *B* close both top and bottom (save only a small hole at *b* to let the air get out of the vessel *B*, and *A* be of such a size, as to hold about six times as much water as *B*. Let a syphon *D E F* be soldered to the vessel *D*, so that the part *D E e* may be within the vessel, and *F* without it; the end *D* almost touching the bottom of the vessel, and the end *F* below the level of *D*: the vessel *B* hanging to *A* by the pipe *C* (soldered into both) and the whole supported by the pillars *G* and *H* upon the stand *I*. The bore of the pipe must be considerably less than the bore of the syphon.

The whole being thus constructed, let the vessel *A* be filled with water, which will run through the pipe *C*, and fill the vessel *B*. When *B* is filled above the top of the syphon at *E*, the water will run through the syphon,

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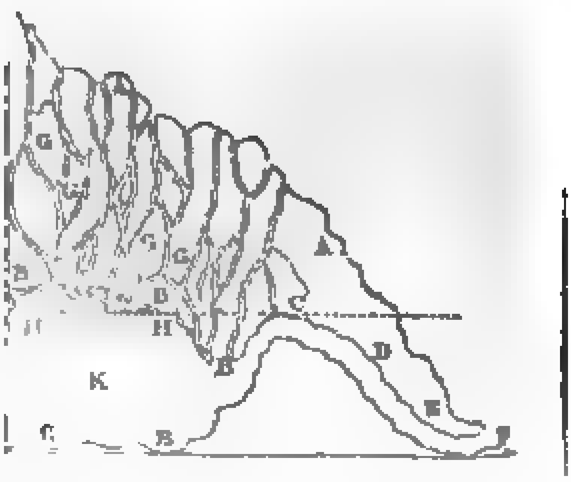
and be discharged at *F*. But as the bore of the syphon is larger than the bore of the pipe, the syphon will run faster than the pipe, and will soon empty the vessel *B*; upon which the water will cease from running through the syphon at *F*, until the pipe *C* re-fills the vessel *B*, and then it will begin to run as before. And thus the syphon will continue to run and stop alternately, until all the water in the vessel *A* has run through the pipe *C*.—So that, after a few trials, one may easily guess about what time the syphon will stop, and when it will begin to run: and then, to amuse others, he may call out *stop*, or *run*, accordingly.

Intermitting springs.

Upon this principle, we may easily account for *intermitting* or *reciprocating springs*. Let *A A* be part of a hill, within which there is a cavity *B B*; and from this cavity a vein or channel running in the direction *B C D E*. The rain that falls upon the side of the hill will sink and strain through the small pores and crannies *G, G, G, G*; and fill the cavity with water *K*. When the water rises to the level *H H C*, the vein *B C D E* will be filled to *C*, and the water will run through *C D F* as through a syphon; which running will continue until the cavity be emptied, and then it will stop until the cavity be filled again.



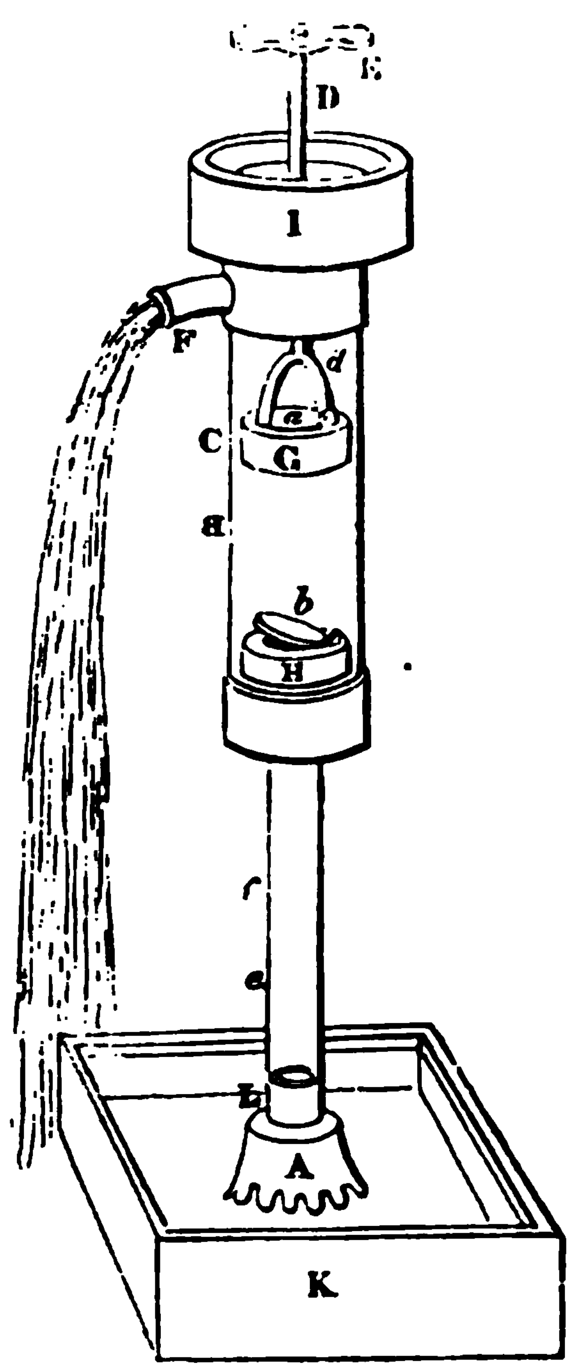
The common pump.

The *common pump* (improperly called the *sucking pump*), with which we draw water out of wells, is an engine both pneumatic and hydraulic. It consists of a pipe open at both ends, in which is a moveable piston or bucket, as big as the bore of the pipe in that part wherein it works; and is leathered round so as to fit the bore exactly; and may be moved up and down, without

suffering any air to come between it and the pipe or pump barrel.

We shall explain the construction both of this and he forcing-pump by pictures of glass models, in which oth the action of the pistons and motion of the valves re seen.

Hold the model *D C B L* pright in the vessel of water [, the water being deep nough to rise at least as igh as from *A* to *L*. The alve *a* on the moveable ucket *G*, and the valve *b* on he fixed box *H*, (which box uite fills the bore of the ipe or barrel at *H*) will ach lie close, by its own weight, upon the hole in the ucket and box, until the engine begins to work. The valves are made of brass, nd lined underneath with eather for closing the holes he more exactly: and the ucket *G* is raised and depressed alternately by the andle *E* and rod *D d*, the ucket being supposed at *B* efore the working begins.



Take hold of the handle *E*, and thereby draw up the ucket from *B* to *C*, which will make room for the air the pump all the way below the bucket to dilate itlf, by which its spring is weakened, and then its force not equivalent to the weight or pressure of the outard air upon the water in the vessel *K*: and therefore, the first stroke, the outward air will press up the ater through the notched foot *A*, into the lower pipe,

LECT. V. about as far as e: this will condense the rarefied air in the pipe between e and C to the same state it was in before; and then, as its spring within the pipe is equal to the force or pressure of the outward air, the water will rise no higher by the first stroke; and the valve b, which was raised a little by the dilatation of the air in the pipe, will fall and stop the hole in the box H; and the surface of the water will stand at e. Then, depress the piston or bucket from C to B, and as the air in the part B cannot get back again through the valve b, it will (as the bucket descends) raise the valve a, and so make its way through the upper part of the barrel d into the open air. But, upon raising the bucket G a second time, the air between it and the water in the lower pipe at a will be again left at liberty to fill a larger space; and so its spring being again weakened, the pressure of the outward air on the water in the vessel K will force more water up into the lower pipe from e to f; and when the bucket is at its greatest height C, the lower valve b will fall, and stop the hole in the box H as before. At the next stroke of the bucket or piston, the water will rise through the box H towards B, and then the valve b, which was raised by it, will fall when the bucket G is at its greatest height. Upon depressing the bucket again, the water cannot be pushed back through the valve b, which keeps close upon the hole whilst the piston descends. And upon raising the piston again, the outward pressure of the air will force the water up through H, where it will raise the valve, and follow the bucket to C. Upon the next depression of the bucket G, it will go down into the water in the barrel B; and, as the water cannot be driven back through the now closed valve b, it will raise the valve a as the bucket descends, and will be lifted up by the bucket when it is next raised. And now, the whole space below the bucket being full, the water above it cannot sink when it is next depressed; but, upon its

depression, the valve *a* will rise to let the bucket go down; and when it is quite down, the valve *a* will fall by its weight, and stop the hole in the bucket. When the bucket is next raised, all the water above it will be lifted up, and begin to run off by the pipe *F*. And thus, by raising and depressing the bucket alternately, there is still more water raised by it; which, getting above the pipe *F*, into the wide top *I*, will supply the pipe, and make it run with a continued stream.

So, at every time the bucket is raised, the valve *b*, rises, and the valve *a* falls; and at every time the bucket is depressed, the valve *b* falls, and *a* rises.

As it is the pressure of the air or atmosphere which causes the water to rise, and follow the piston or bucket *G* as it is drawn up; and since a column of water 33 feet high is of equal weight with as thick a column of the atmosphere, from the earth to the very top of the air; therefore, the perpendicular height of the piston or bucket from the surface of the water in the well must always be less than 33 feet; otherwise the water will never get above the bucket. But, when the height is less, the pressure of the atmosphere will be greater than the weight of the water in the pump, and will therefore raise it above the bucket: and when the water has once got above the bucket, it may be lifted thereby to any height, if the rod *D* be made long enough, and a sufficient degree of strength be employed, to raise it with the weight of the water above the bucket.

The force required to work a pump will be as the height to which the water is raised, and as the square of the diameter of the pump-bore, in that part where the piston works. So that, if two pumps be of equal heights, and one of them be twice as wide in the bore as the other, the widest will raise four times as much water as the narrowest: and will therefore require four times as much strength to work it.

The wideness or narrowness of the pump, in any

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other part besides that in which the piston works, does not make the pump either more or less difficult to work, except what difference may arise from the friction of the water in the bore; which is always greater in a narrow bore than in a wide one, because of the greater velocity of the water.[46] The pump-rod is never raised directly by such a handle as *E* at the top, but by means of a lever, whose longer arm (at the end of which the power is applied) generally exceeds the length of the shorter arm five or six times; and, by that means, it gives five or six times as much advantage to the power. Upon these principles, it will be easy to find the dimensions of a pump that shall work with a given force, and draw water from any given depth. But, as these calculations have been generally neglected by pump-makers, (either for want of skill or industry) the following table was calculated by the late ingenious Mr. *Booth* for their benefit. In this calculation, he supposed the handle of the pump to be a lever increasing the power five times; and had often found that a man can work a pump four inches diameter, and 30 feet high, and discharge 27¼ gallons of water (English wine measure) in a minute. Now, if it be required to find the diameter of a pump, that shall raise water with the same ease, from any other height above the surface of the *well;* look for that height in the first column, and over-against it, in the second, you have the diameter or width of the pump; and in the third, you find the quantity of water which a man of ordinary strength can discharge in a minute.

Note 46. Should the disproportion between the suction-pipe and piston-barrel be very considerable, the labour of working the pump will be materially increased. Instances, however, have occurred, in which pumps have been so constructed as to raise cannon-balls by the momentum of the ascending column of water; and when hydraulic engines are constructed for the use of vessels, this mode of increasing the velocity of the water appears well adapted to prevent the pump choking or becoming foul.

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leight of the pump above the surface of the well.	Diameter of the bore where the bucket works.		Water discharged in a minute, English wine measure.	
Feet.	Inches.	100 parts.	Gallons.	Pints.
10	6	.93	81	6
15	5	.66	54	4
20	4	.90	40	7
25	4	.38	32	6
30	4	.00	27	2
35	3	.70	23	3
40	3	.46	20	3
45	3	.27	18	1
50	3	.10	16	3
55	2	.95	14	7
60	2	.84	13	5
65	2	.72	12	4
70	2	.62	11	5
75	2	.53	10	7
80	2	.45	10	2
85	2	.38	9	5
90	2	.31	9	1
95	2	.25	8	5
100	2	.19	8	1

The forcing-pump.

Phe *forcing-pump* raises water through the box *H* in same manner as the sucking pump does, when the inger or piston *g* is lifted up by the rod *D d*. But s plunger has no hole through it, to let the water in barrel *B C* get above it, when it is depressed to *B*, l the valve *b* (which rose by the ascent of the water ough the box *H* when the plunger *g* was drawn up) ls down and stops the hole in *H*, the moment that the

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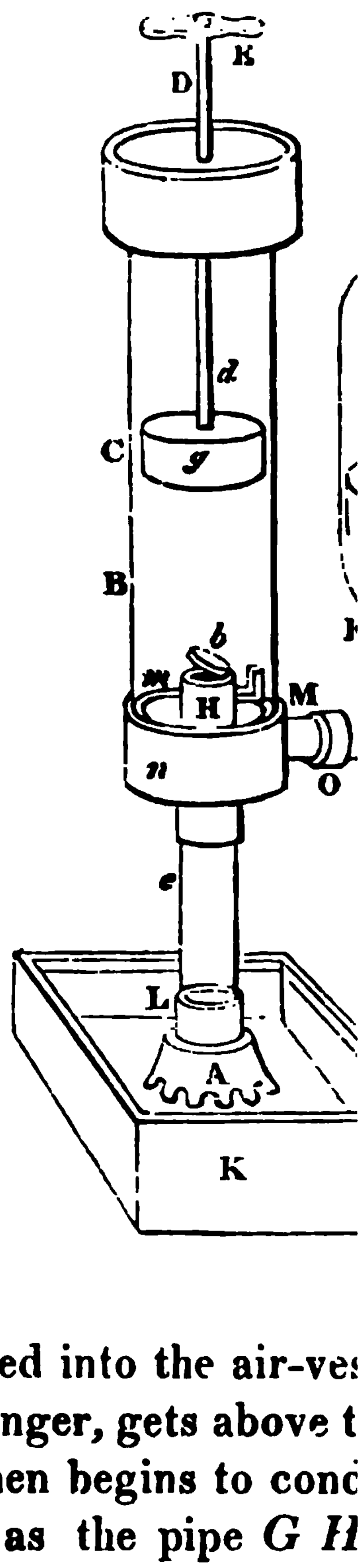
plunger is raised to its greatest height. Therefore, as the water between the plunger *g* and box *H* can neither get through the plunger upon its descent, nor back again into the lower part of the pump *L e*, but has a free passage by the cavity around *H* into the pipe *M M*, which opens into the air-vessel *K K* at *P*; the water is forced through the pipe *M M* by the descent of the plunger, and driven into the air-vessel; and in running up through the pipe at *P*, it opens the valve *a*; which shuts at the moment the plunger begins to be raised, because the action of the water against the under side of the valve then ceases.



The water, being thus forced into the air-ve by repeated strokes of the plunger, gets above t end of the pipe *G H I*, and then begins to conc air in the vessel *K K*. For, as the pipe *G H* air-tight into the vessel below *F*, and the air ha to get out of the vessel but through the mou pipe at *I*, and cannot get out when the mouth vered with water, and is more and more cond the water rises upon the pipe, the air then begi forcibly by its spring against the surface of the *H*: and this action drives the water up thr pipe *I H G F*, from whence it spouts in a je great height; and is supplied by alternately rai depresssing of the plunger *g*, which constant

the water that it rises through the valve *H*, along the pipe *MM*, into the air-vessel *KK*.

The higher that the surface of the water *H* is raised in the air-vessel, the less space will the air be condensed into, which before filled that vessel; and therefore the force of its spring will be so much the stronger upon the water, and will drive it with the greater force through the pipe at *F*: and as the spring of the air continues whilst the plunger *g* is rising, the stream or jet *S* will be uniform, as long as the action of the plunger continues: and when the valve *b* opens, to let the water follow the plunger upward, the valve *a* shuts, to hinder the water, which is forced into the air-vessel, from running back by the pipe *MM* into the barrel of the pump.

If there was no air-vessel to this engine, the pipe *GHI* would be joined to the pipe *MMN* at *P*; and then, the jet *S* would stop every time the plunger is raised, and run only when the plunger is depressed.

Mr. *Newsham's* water-engine for extinguishing fire, consists of two forcing-pumps, which alternately drive water into a close vessel of air; and by forcing the water into that vessel, the air in it is thereby condensed, and compresses the water so strongly, that it rushes out with great impetuosity and force through a pipe that comes down into it; and makes a continued uniform stream by the condensation of the air upon its surface in the vessel.

By means of forcing-pumps, water may be raised to any height above the level of a river or spring; and machines may be contrived to work these pumps, either by a running stream, a fall of water, or by horses. An instance in each sort will be sufficient to shew the method.

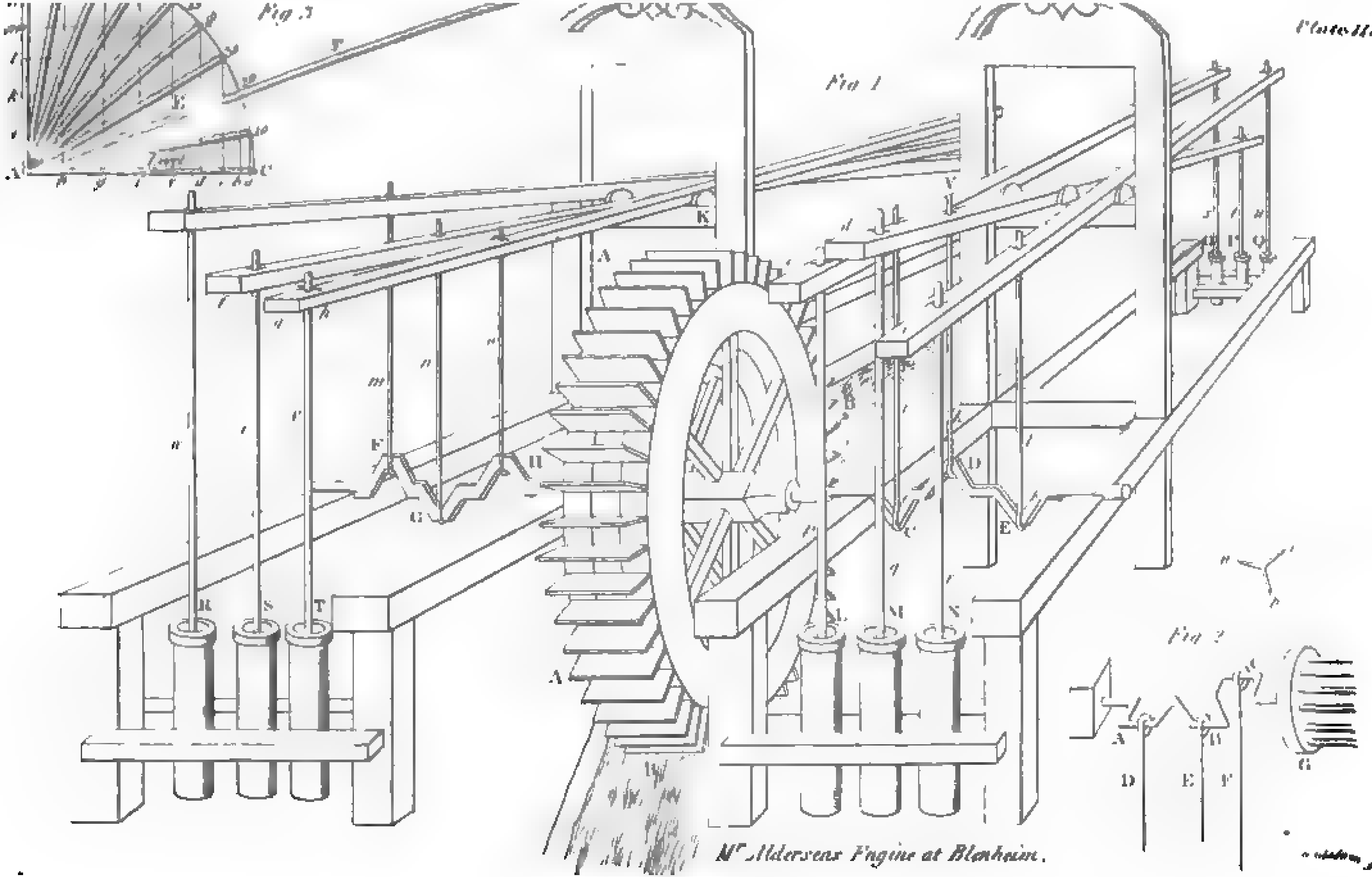
First, by a running stream, or a fall of water. Let *A A* (Plate III.) be a wheel, turned by the fall of water *B B*; and have any number of cranks (suppose 6) as *C*, *D*, *E*, *F*,

G, H, upon its axis, according to the strength of the fall of water, and the height to which the water is intended to be raised by the engine, as the wheel turns round, these cranks move the levers *c, d, e, f, g, h*, up and down, by the iron rods *i, k, l, m, n, o*; which alternately raise and depress the pistons by the other iron rods *p, q, r, s, t, u, w, x, y*, in twelve pumps; nine whereof, as *L, M, N, O, P, Q, R, S, T*, appear in the plate; the other three being hid behind the work at *V*. And as pipes may go from all these pumps, to convey the water (drawn up by them to a small height) into a close cistern, from which the main pipe goes off, the water will be forced into this cistern by the descent of the pistons. And as each pipe going from its respective pump into the cistern, has a valve at its end in the cistern, these valves will hinder the return of the water by the pipes; and therefore, when the cistern is once full, each piston upon its descent will force the water (conveyed into the cistern by a former stroke) up the main pipe, to the height the engine was intended to raise it which height depends upon the quantity raised, and the power that turns the wheel. When the power upon the wheel is lessened by any defect of the quantity of water turning it, a proportionable number of the pumps may be laid aside, by disengaging their rods from the vibrating levers.

This figure is a representation of the engine erected at *Blenheim* for the Duke of *Marlborough*, by the late ingenious Mr. *Aldersea*. The water wheel is 7½ feet in diameter, according to Mr. *Switzer's* account in his Hydraulics.

When such a machine is placed in a stream that runs upon a small declivity, the motion of the levers and action of the pumps will be but slow; since the wheel must go once round for each stroke of the pumps. But when there is a large body of slow running water, a cog or spur wheel may be placed upon each side of the

Plate III



Mr. Aldersons Engine at Blenheim.

water-wheel, *A A*, upon its axis, to turn a trundle upon each side; the cranks being upon the axis of the trundle. And by proportioning the cog-wheels to the trundles, the motion of the pumps may be made quicker, according to the quantity and strength of the water upon the first wheel; which may be as great as the workman pleases; according to the length and breadth of the float-boards or wings of the wheel. In this manner, the engine for raising water at *London-Bridge* was constructed; in which, the water-wheel being 20 feet diameter, and the floats 14 feet long.

A pump-engine to go by horses.

Where a stream or fall of water cannot be had, and gentlemen want to have water raised, and brought to their houses from a rivulet or spring: this may be effected by a horse-engine, working three forcing-pumps which stand in a reservoir filled by the spring or rivulet: the pistons being moved up and down in the pumps by means of a triple crank *A B C*, (Plate III.) which, as it is turned round by the trundle *G*, raises and depresses the rods *D,E,F*. The trundle may be turned by such a wheel as *F* in Plate II. having levers *y, y, y, y*, on its upright axle, to which horses may be joined for working the engine. And if the wheel has three times as many cogs as the trundle has staves or rounds, the trundle and cranks will make three revolutions for every one of the wheel: and as each crank will fetch a stroke in the time it goes round, the three cranks will make nine strokes for every turn of the great wheel.

The cranks should be made of cast iron, because *that* will not bend; and they should each make an angle of 120° with both of the others, as at *a, b, c*, which is (as it were) a view of their *radii*, in looking endwise at the axis: and then there will be always one or other of them going downward, which will push the water forward with a continued stream into the main pipe. For, when *b* is almost at its lowest situation, and is therefore just beginning to lose its action upon the piston which it

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moves, *c* is beginning to move downward, which will by its piston continue the propelling force upon the water: and when *c* is come down to the position of *b*, *a* will be in the position of *c*.

The more perpendicularly the piston rods move up and down in the pumps, the freer and better will their strokes be: but a little deviation from the perpendicular will not be material. Therefore, when the pump-rods *D*, *E*, and *F* go down into a deep well, they may be moved directly by the cranks, as is done in a very good horse-engine of this sort at the late Sir *James Creed's*, at *Greenwich*, which forces up water about 64 feet from a well under ground, to a reservoir on the top of his house. But when the cranks are only at a small height above the pumps, the pistons must be moved by vibrating levers, as in the above engine at *Blenheim*; and the longer the levers are, the nearer will the strokes be to a perpendicular.

A calculation of the quantity of water that may be raised by a horse engine.

Let us suppose that in such an engine as Sir *James Creed's*, the great wheel is 12 feet diameter, the trundle 4 feet, and the radius or length of each crank 9 inches, working a piston in its pump. Let there be three pumps in all, and the bore of each pump be four inches diameter. Then, if the great wheel has three times as many cogs as the trundle has staves, the trundle and cranks will go three times round for each revolution of the horses and wheel, and the three cranks will make nine strokes of the pumps in that time, each stroke being 18 inches (or double the length of the crank) in a four-inch bore. Let the diameter of the horse-walk be 18 feet, and the perpendicular height to which the water is raised above the surface of the well be 64 feet.

If the horses go at the rate of two miles an hour (which is very moderate walking) they will turn the great wheel 187 times round in an hour.

In each turn of the wheel the pistons make 9 strokes in the pumps, which amount to 1683 in an hour.

Each stroke raises a column of water 18 inches long, and four inches thick, in the pump barrels; which column, upon the descent of the piston, is forced into the main pipe, whose perpendicular altitude above the surface of the well is 64 feet.

Now, since a column of water 18 inches long, and 4 inches thick, contains 226.18 cubic inches, this number multiplied by 1683 (the strokes in an hour) gives 380661 for the number of cubic inches of water raised in an hour.

A gallon, in wine measure, contains 231 cubic inches, by which divide 380661, and it quotes 1468 in round numbers, for the number of gallons raised in an hour; which, divided by 63, gives $26\frac{1}{3}$ hogsheads.—If the horses go faster, the quantity raised will be so much the greater.

In this calculation it is supposed that no water is wasted by the engine. But as no forcing engine can be supposed to lose less than a fifth part of the calculated quantity of water, between the pistons and barrels, and by the opening and shutting of the valves, the horses ought to walk almost $2\frac{1}{4}$ miles *per* hour, to fetch up this loss.

A column of water 4 inches thick, and 64 feet high, weighs $340\frac{1}{16}$ pounds avoirdupoise, or $424\frac{5}{18}$ pounds troy; and this weight, together with the friction of the engine, is the resistance that must be overcome by the strength of the horses.

The horse-tackle should be so contrived, that the horses may rather push on than drag the levers after them. For if they draw, in going round the walk, the outside leather straps will rub against their sides and hams; which will hinder them from drawing at right angles to the levers, and so make them pull at a disadvantage. But if they push the levers before their breasts, instead of dragging them, they can always walk at right angles to these levers.

It is no ways material what the diameter of the main or conduct pipe be: for the whole resistance of the wa-

LECT V. ter therein, against the horses will be according to the height to which it is raised, and the diameter of that part of the pump in which the piston works, as we have already observed. So that, by the same pump, an equal quantity of water may be raised in (and consequently made to run from) a pipe of a foot diameter, with the same ease as in a pipe of five or six inches : or rather with more ease, because its velocity in a large pipe will be less than in a small one; and therefore its friction against the sides of the pipe will be less also.[47]

Note 47. Our attention may now be directed to some of the different forms which may be given to the pistons and valves of a pump.

The great desideratum in a piston is, that while it be as tight as possible, it should have as little friction as is consistent with this indispensable quality. The common form, when carefully executed, possesses these properties in an eminent degree. This piston is a sort of truncated cone, generally made of wood not apt to split, such as helm or beech. The small end of it is cut off at the sides, so as to form a sort of arch, by which it is fastened to the iron rod or spear. The two ends of the conical part may be hooped with brass. This cone has its larger end surrounded with a ring or band of strong leather fastened with nails, or by a copper hoop, which is driven on it at the smaller end. The further this band reaches beyond the base of the cone, the better; and the whole must be of uniform thickness all round, so as to suffer equal compression between the cone and working barrel. The seam or joint of the two ends of this band must be made very close; but not sewed or stiched together, as that would occasion bumps or inequalities, which would spoil its tightness; and no harm can result from the want of it, because the two edges will be squeezed close together by the compression in the barrel. Nor is it by any means necessary that this compression be great: this is a very detrimental error of the pump-makers. It occasions enormous friction, and destroys the very purpose which they have in view, viz. rendering the piston air-tight; for it causes the leather to wear through very soon at the edge of the cone, and it also wears the working barrel. This very soon becomes wide in that part which is continually passed over by the piston, while the mouth remains of its original diameter, and it becomes impossible to thrust in a piston which shall completely fill the worn part. Now a very moderate pressure is sufficient for rendering the pump perfectly tight, and a piece of glove-leather would be sufficient for this purpose, if loose or detached from

And the force required to raise water depends not upon the length of the pipe, but upon the perpendicular height to which it is raised therein above the level of LECT V.

the solid cone; for suppose such a loose and flexible, but impervious, band of leather put round the piston, and put into the barrel; and let it even be supposed that the cone does not compress it in the smallest degree to its internal surface. Pour a little water carefully into the inside of this sort of cup or dish; it will cause it to swell out a little and apply itself close to the barrel all round, and even adjust itself to all its inequalities. Let us suppose it to touch the barrel in a ring of an inch broad all round. We can easily compute the force with which it is pressed. It is half the weight of a ring of water an inch deep and an inch broad. This is a trifle, and the friction occasioned by it not worth regarding; yet this trifling pressure is sufficient to make the passage perfectly impervious, even by the most enormous pressure of a high column of incumbent water: for let this pressure be ever so great, the pressure by which the leather adheres to the barrel always exceeds it, because the incumbent fluid has no *preponderating* power by which it can force its way between them, and it must insinuate itself precisely so far, that its pressure on the inside of the leather shall still exceed, and only exceed, the pressure by which it endeavours to insinuate itself: and thus the piston becomes perfectly tight with the smallest possible friction. This reasoning is perhaps too refined for the uninstructed artist, and probably will not persuade him. To such we would recommend an examination of the pistons and valves contrived and executed by that artist, whose skill far surpasses our highest conceptions, the all-wise Creator of this world. The valves which shut up the passages of the veins, and this in places where an extravasation would be followed by instant death, are cups of thin membrane, which adhere to the sides of the channel about half way round, and are detached in the rest of their circumference. When the blood comes in the opposite direction, it pushes the membrane aside, and has a passage perfectly free. But a stagnation of motion allows the tone of the (perhaps) muscular membrane, to restore it to its natural shape, and the least *motion* in the opposite direction causes it instantly to clap close to the sides of the veins, and then no pressure whatever can force a passage. We shall recur to this again when describing the various contrivances of valves, &c. What we have said is enough for supporting our directions for constructing a tight piston. But we recommend thick and strong leather, while our present reasoning seems to render thin leather preferable. If the leather be thin, and the solid piston in any part does not press it gently to the barrel, there will be in this part an unbalanced pressure of the incumbent column of water, which would instantly burst even a strong leather bag: but

LECT. V. the spring. So that the same force, which would raise water to the height *A B* in the upright pipe *A i k l m n o p q B*, will raise it to the same height or level *B I H* in the oblique pipe *A E F G H*. For the pressure of the water at the end *A* of the latter is no more than its pressure against the end *A* of the former.

The weight or pressure of water at the lower end of the pipe, is always as the sine of the angle to which the pipe is elevated above the level parallel to the horizon. For, although the water in the upright pipe *A B* would require a force applied immediately to the lower end *A* equal to the weight of all the water in it, to support the water, and a little more to drive it up, and out of the pipe; yet, if that pipe be inclined from its upright position to an angle of 80 degrees (as in *A* 80) the force required to support or to raise the same cylinder of water will then be as much less, as the sine 80 *h* is less than the radius *A B*; or as the sine of 80 degrees is less than the sine of 90. And so, decreasing as the sine of the angle of elevation lessens, until it arrives at its level *A C* or place of rest, where the force of the water is nothing at either end of the pipe. For, although the absolute weight of the water is the same in all positions, yet its pressure at the lower end decreases, as the sine of the angle of elevation decreases; as will appear plainly by a farther consideration of the figure.

Let two pipes, *A B* and *AC*, (Plate III.) of equal lengths and bores, join each other at *A*; and let the pipe *A B* be divided into 100 equal parts, as the scale *S* is; whose

when the solid piston covered with leather, exactly fills the barrel, and is even pressed a little to it, there is no such risk; and now that part of the leather band which reaches beyond the solid piston performs its office in the completest manner. We do not hesitate, therefore, to recommend this form of a piston, which is the most common and simple of all, as preferable, when well executed, to many of those more artificial, and frequently very ingenious, constructions, which we have met with in the works of the first engineers.—*Vide Gregory on Practical Mechanics.*

length is equal to the length of the pipe.—Upon this length, as a radius, describe the quadrant *B D C*, and divide it into 90 equal parts or degrees.

Let the pipe *A C* be elevated to 10 degrees upon the quadrant, and filled with water; then part of the water that is in it will rise in the pipe *A B*, and if it be kept full of water, it will raise the water in the pipe *A B* from *A* to *i*; that is, to a level *i* 10 with the mouth of the pipe at 10: and the upright line *a* 10 equal to *A i*, will be the sine of 10 degrees' elevation; which, being measured upon the scale *S*, will be about 17.4 of such parts as the pipe contains 100 in length: and therefore, the force or pressure of the water at *A* in the pipe *A* 10, will be to the force or pressure at *A* in the pipe *A B*, as 17.3 to 100.

Let the same pipe be elevated to 20 degrees in the quadrant, and if it be kept full of water, part of that water will run into the pipe *A B*, and rise therein to the height *A k*, which is equal to the length of the upright line *b* 20, or to the sine of 20 degrees' elevation; which, being measured upon the scale *S*, will be 34.2 of such parts as the pipe contains 100 in length. And therefore, the pressure of the water at *A*, in the full pipe *A* 20, will be to its pressure, if that pipe were raised to the perpendicular situation *A B*, as 34.2 to 100.

Elevate the pipe to the position *A* 30 on the quadrant, and if it be supplied with water, the water will rise from it into the pipe *A B*, to the height *A l*, or to the same level with the mouth of the pipe at 30. The sine of this elevation, or of the angle of 30 degrees, is *c* 30; which is just equal to half the length of the pipe, or to 50 of such parts of the scale, as the length of the pipe contains 100. Therefore, the pressure of the water at *A*, in a pipe elevated 30 degrees above the horizontal level, will be equal to one half of what it would be if the same pipe stood upright in the situation *A B*.

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And thus, by elevating the pipe, to 40, 50, 60, 70 and 80 degrees on the quadrant, the sines of these elevations will be *d* 40, *e* 50, *f* 60, *g* 70, and *h* 80

Sine of	Parts	Sine of	Parts	Sine of	Parts
D. 1	17	D. 31	515	D. 61	875
2	35	32	530	62	883
3	52	33	545	63	891
4	70	34	559	64	899
5	87	35	573	65	906
6	104	36	588	66	913
7	122	37	602	67	920
8	139	38	616	68	927
9	156	39	629	69	934
10	174	40	643	70	940
11	191	41	656	71	945
12	208	42	669	72	951
13	225	43	682	73	956
14	242	44	695	74	961
15	259	45	707	75	966
16	276	46	719	76	970
17	292	47	731	77	974
18	309	48	743	78	978
19	325	40	755	79	982
20	342	50	766	80	985
21	358	51	777	81	988
22	375	52	788	82	990
23	391	53	799	83	992
24	407	54	809	84	994
25	423	55	819	85	996
26	438	56	829	86	997
27	454	57	839	87	998
28	469	58	848	88	999
29	485	59	857	89	1000
30	500	60	866	90	1000

which will be equal to the heights $A\,m$, $A\,n$, $A\,o$, $A\,p$, and $A\,q$: and these heights, measured upon the scale S, will be 64.3, 76.6, 86.6, 94.0, and 98.5; which express the pressures at A in all these elevations, considering the pressure in the upright pipe $A\,B$ as 100.

Because it may be of use to have the lengths of all the sines of a quadrant from 0 degrees to 90, we have given the foregoing table, shewing the length of the sine of every degree in such parts as the whole pipe (equal to the radius of the quadrant) contains 1000. Then the sines will be integral or whole parts in length. But if you suppose the length of the pipe to be divided only into 100 equal parts, the last figure of each part or sine must be cut off as a decimal; and then those which remain at the left hand of this separation will be integral or whole parts.

Thus, if the radius of the quadrant (supposed to be equal to the length of the pipe $A\,C$) be divided into 1000 equal parts, and the elevation be 45 degrees, the sine of that elevation will be equal to 707 of these parts: but if the radius be divided only into 100 equal parts, the same sine will be only 70.7, or $70\frac{7}{10}$ of these parts. For, as 1000 is to 707, so is 100 to 70.7.

As it is of great importance to all engine-makers, to know what quantity and weight of water will be contained in an upright round pipe of a given diameter and height, so that, by knowing what weight is to be raised, they may proportion their engines to the force which they can afford to work them; we shall subjoin tables shewing the number of cubic inches of water contained in an upright pipe of a round bore, of any diameter from one inch to six and a half; and of any height from one foot to two hundred: together with the weight of the said number of cubic inches, both in troy and avoirdupoise ounces. The number of cubic inches divided by 231, will reduce the water to gallons in wine measure; and divided by 282 will reduce it to the measure

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of ale gallons. Also, the troy ounces divided l will reduce the weight to troy pounds; and the dupoise ounces divided by 16, will reduce the wei avoirdupoise pounds.

And here I must repeat it again, that the wei pressure of the water acting against the powe works the engine, must always be estimated acc to the perpendicular height to which it is to be without any regard to the length of the conduc when it has an oblique position; and as if the ter of that pipe were just equal to the diameter o part of the pump in which the piston works. Th the following tables, the pressure of the water, a an engine whose pump is of a 4½ inch bore, a perpendicular height of the water in the conduc is 80 feet, will be equal to 8057.5 troy ounces, a 8848.2 avoirdupoise ounces; which makes 671.4 pounds, and 553 avoirdupoise.

EXAMPLE. *Required the number of cubic inche the weight of the water, in an upright pipe 278 fee and 1½ inch diameter?*

	Feet	Cubic inches	Troy oz.	Avoird. oz.
	200	4241.1	2238.2	2457.8
	70	1484.4	783.3	860.2
	8	169.6	89.5	98.3
Ans.	278	5895.1	3111.0	3416.3

Here the nearest single decimal figure only is into the account: and the whole being reduc division, amounts to 25½ wine gallons in measu 259¼ pounds troy; and to 213½ pounds avoirdupoi

For any bore whose diameter exceeds 6½ i multiply the numbers on the following page a any height (belonging to 1 inch diameter) by the s

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1 Inch diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir-dupoise ounces.
1	9.42	4.97	5.46
2	18.85	9.95	10.92
3	28.27	14.92	16.38
4	37.70	19.89	21.85
5	47.12	24.87	27.31
6	56.55	29.84	32.77
7	65.97	34.82	38.23
8	75.40	39.79	43.69
9	84.82	44.76	49.16
10	94.25	49.74	54.62
20	188.49	99.48	109.24
30	282.74	149.21	163.86
40	376.99	198.95	218.47
50	471.24	248.69	273.09
60	565.49	298.43	327.71
70	659.73	348.17	382.33
80	753.98	397.90	436.95
90	848.23	447.64	491.57
100	942.48	497.38	546.19
200	1884.96	994.76	1092.38

of the diameter of the given bore, and the products will be the number of cubic inches, troy ounces, and avoirdupoise ounces of water, that the given bore will contain.

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1¼ Inch diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	I ((
1	21.21	11.19	
2	42.41	22.38	
3	63.62	33.57	
4	84.82	44.76	
5	106.03	55.95	
6	127.23	67.15	
7	147.44	78.34	
8	169.65	89.53	
9	190.85	100.72	
10	212.06	111.91	
20	424.12	223.82	
30	636.17	335.73	
40	848.23	447 64	
50	1060.29	559.55	
60	1272.35	671.46	
70	1484.40	783.37	
80	1696.46	895.28	
90	1908.52	1007.19	1
100	2120.58	1119.10	1
200	4241.15	2238.20	2

These tables were at first calculated to places for the sake of exactness ; but in them there are no more than two decimal into the account, and sometimes but or

2 Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	37.70	19.89	21.85
2	75.40	39.79	43.69
3	113.10	59.68	65.54
4	150.80	79.58	87.39
5	188.50	99.47	109.24
6	226.19	119.37	131.08
7	263.89	139.26	152.93
8	301.59	159.16	174.78
9	339.29	179.06	196.63
10	376.99	198.95	218.47
20	753.98	397.90	436.95
30	1130.97	596.85	655.42
40	1507.97	795.80	873.90
50	1884.96	994.75	1092.37
60	2261.95	1193.70	1310.85
70	2638.94	1392.65	1529.32
80	3015.93	1591.60	1747.80
90	3392.92	1790.56	1966.27
100	3769.91	1989.51	2184.75
200	7539.82	3979.00	4369.50

there is no necessity for computing to hundredth parts of an inch or of an ounce in practice. And as they never appeared in print before, it may not be amiss to give the reader an account of the principles upon which they were constructed.

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2¼ Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	58.90	31.08	34.14
2	117.81	62.17	68.27
3	176.71	93.26	102.41
4	235.62	124.34	136.55
5	294.52	155.43	170.68
6	353.13	186.52	204.82
7	412.33	217.60	238.96
8	471.24	248.69	273.09
9	530.14	279.77	307.23
10	589.05	310.86	341.37
20	1178.10	621.72	682.73
30	1767.15	932.58	1024.10
40	2356.20	1243.44	1365.47
50	2545.25	1554.30	1706.83
60	3534.29	1865.16	2048.20
70	4123.34	2176.02	2389.57
80	4712.39	2486.88	2730.94
90	5301.44	2797.74	3072.30
100	5890.49	3108.60	2413.67
200	11780.98	6217.20	4827.34

The solidity of cylinders is found by multiplying th areas of their bases by their altitudes. And ARCH MEDES gives the following proportion for finding th area of a circle, and the solidity of a cylinder raise upon that circle :

3 Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	84.8	44.76	49.16
2	169.6	89.53	98.31
3	254.5	134.29	147.47
4	339.3	179.06	196.63
5	424.1	223.82	245.78
6	508.9	268.58	294.94
7	593.7	313.35	344.10
8	698.6	358.11	393.25
9	763.4	402.87	442.41
10	848.2	447.64	491.57
20	1696.5	895.28	983.14
30	2544.7	1342.92	1474.70
40	3392.9	1790.56	1966.27
50	4241.1	2238.19	2457.84
60	5089.4	2685.83	2949.41
70	5937.6	3133.47	3440.98
80	6785.8	3581.11	3932.55
90	7634.1	4028.75	4424.12
100	8482.3	4476.39	4915.68
200	16964.6	8952.78	9831.36

As 1 is to 0.785399, so is the square of the diameter to the area of the circle. And as 1 is to 0.785399, so is the square of the diameter multiplied by the height to the solidity of the cylinder. By this analogy, the solid inches and parts of an inch in the tables are cal-

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3¼ Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoir-dupoise ounces.
1	115.4	60.9	66.9
2	230.9	121.8	133.8
3	346.4	182.8	200.7
4	461.8	243.7	267.6
5	577.3	304.6	334.5
6	692.7	365.6	401.4
7	808.2	426.5	468.4
8	923.6	487.4	535.3
9	1039.1	548.4	602.2
10	1154.5	609.3	669.1
20	2309.1	1218.6	1338.2
30	3463.6	1827.9	2007.2
40	4618.1	2437.1	2676.3
50	5772.7	3046.4	3345.4
60	6927.2	3655.7	4014.5
70	8081.8	4265.0	4683.6
80	9236.3	4874.3	5352.6
90	10390.8	5483.6	6021.7
100	11545.4	6092.9	6690.8
200	23090.7	12185.7	13381.5

culated to a cylinder 200 feet high, of any diam from 1 inch to 6¼, and may be continued at pleasure.

The weight of running water.

And as to the weight of a cubic foot of runn water, it has been often found upon trial, by Dr. *Wyl* and others, to be 76 pounds troy, which is equal

4 Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	150.8	79.6	87.4
2	301.6	159.2	174.8
3	452.4	238.7	262.2
4	603.2	318.3	349.6
5	754.0	397.9	436.9
6	904.8	477.5	524.3
7	1055.6	557.1	611.7
8	1206.4	636.6	699.1
9	1357.2	716.2	786.5
10	1508.0	795.8	873.9
20	3115.9	1591.6	1747.8
30	4523.9	2387.4	2621.7
40	6031.9	3183.2	3495.6
50	7539.8	3997.0	4369.5
60	9047.8	4774.8	5243.4
70	10555.8	5570.6	6117.3
80	12063.7	6366.4	6991.2
90	13571.7	7162.2	7865.1
100	15079.7	7958.0	8739.0
200	30159.3	15916.0	17478.0

62.5 pounds avoirdupoise. Therefore, since there are 1728 cubic inches in a cubic foot, a troy ounce of water contains 1.8949 cubic inch; and an avoirdupoise ounce of water 1.72556 cubic inch. Consequently, if the number of cubic inches contained in any given cylinder, be

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4¼ Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In a dup oun
1	190.8	100.7	1
2	381.7	201.4	2
3	572.6	302.2	3
4	763.4	402.9	4
5	954.3	503.6	5
6	1145.1	604.3	6
7	1338.0	705.0	7
8	1526.8	805.7	8
9	1717.7	906.5	9
10	1908.5	1007.2	11
20	3817.0	2014.4	22
30	5725.6	3021.6	38
40	7634.1	4028.7	44
50	9542.6	5035.9	55
60	11451.1	6043.1	66
70	13359.6	7050.3	77
80	15268.2	8057.5	88
90	17176.7	9064.7	99
100	19085.2	10071.9	110
200	38170.4	20143.8	221

divided by 1.8949, it will give the weight in tro and divided by 1.72556, will give the weighl dupoise ounces. By this method, the weights the tables were calculated; and are near e any common practice.

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5 Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	235.6	124.3	136.5
2	471.2	248.7	273.1
3	706.9	373.0	409.6
4	942.5	497.4	546.2
5	1178.1	621.7	682.7
6	1413.7	746.1	819.3
7	1649.3	870.4	955.8
8	1885.0	994.8	1092.4
9	2120.6	1119.1	1228.9
10	2356.2	1243.4	1365.5
20	4712.4	2486.9	2730.9
30	7068.6	3730.3	4096.4
40	9424.8	4973.8	5461.9
50	11780.0	6217.2	6827.3
60	14137.2.	7460.6	8192.8
70	16493.4	8704.1	9558.3
80	18849.6	9947.5	10923.7
90	21205.8	11191.0	12289.2
100	23562.0	12434.4	13654.7
200	47124.0	24868.8	27309.3

The *fire-engine* comes next in order to be explained; but as it would be difficult, even by the best plates, to give a particular description of its several parts, so as to make the whole intelligible, I shall only explain the principles upon which it is constructed.

The *fire-engine.*

LECT V.

5¼ Inches diameter.			
Feet high	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	285.1	150.5	164.3
2	570.2	300.9	328.5
3	855.3	451.4	492.8
4	1140.4	601.8	657.1
5	1425.5	752.3	821.3
6	1710.6	902.7	985.6
7	1995.7	1053.2	1149.9
8	2280.8	1203.6	1314.2
9	2565.9	1354.1	1478.4
10	2851.0	1504.6	1642.7
20	5702.0	3009.1	3285.4
30	8553.0	4513.7	4928.1
40	11404.0	6018.2	6570.8
50	14255.0	7522.8	8213.5
60	17106.0	9027.4	9856.2
70	19957.0	10531.9	11498.9
80	22808.0	12036.5	13141.6
90	25659.0	13541.1	14784.3
100	28510.0	12045.6	16426.9
200	57020.0	30091.2	32853.9

1. Whatever weight of water is to be raised, pump-rod must be loaded with weights sufficient that purpose, if it be done by a forcing-pump as is nerally the case; and the power of the engine must sufficient for the weight of the rod, in order to bring it

LECT. I.

6 Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	339.3	179.1	196.6
2	678.6	358.4	393.3
3	1017.9	537.2	589.9
4	1357.2	716.2	786.5
5	1696.5	895.3	983.1
6	2035.7	1074.3	1179.8
7	2375.0	1253.4	1376.4
8	2714.3	1432.4	1573.0
9	3053.6	1611.5	1769.6
10	3392.9	1790.6	1966.3
20	6785.8	3581.1	3932.5
30	10178.8	5371.7	5898.8
40	13571.7	7162.2	7865.1
50	16964.6	8952.8	9831.4
60	20357.5	10743.3	11797.6
70	23750.5	12533.9	13763.9
80	27143.4	14324.4	15730.2
90	30536.3	16115.0	17696.5
100	33929.2	17905.6	19662.7
200	67858.4	35811.2	39325.4

2. It is known, that the atmosphere presses upon the surface of the earth with a force equal to 15 pounds upon every square inch.

3. When water is heated to a certain degree, the particles thereof repel one another, and constitute an elastic fluid, which is generally called *steam* or *vapour*.

LECT V

6½ Inches diameter.			
Feet high.	Quantity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	398.2	210.1	230.7
2	797.4	420.3	461.4
3	1195.6	630.4	692.1
4	1593.8	840.6	922.8
5	1991.9	1050.8	1153.6
6	2390.1	1260.9	1384.3
7	2788.3	1471.1	1615.0
8	3186.5	1681.2	1845.7
9	3584.7	1891.3	2076.4
10	3982.9	2101.5	2307.1
20	7965.8	4202.9	4614.3
30	11948.8	6304.4	6921.4
40	15931.7	8405.9	9228.6
50	19914.6	10507.4	11535.7
60	23897.6	12608.9	13842.9
70	27880.5	14710.4	16150.0
80	31863.4	16811.8	18457.2
90	35846.3	18913.3	20764.3
100	39829.3	21014.8	23071.5
200	79658.6	42029.6	46143.0

4. Hot steam is very elastic; and when it is cooled by any means, particularly by its being mixed with cold water, its elasticity is destroyed immediately, and it is reduced to water again.

5. If a vessel be filled with hot steam, and then closed so as to keep out the external air, and all other fluids

when that steam is by any means condensed, cooled, or reduced to water, *that* water will fall to the bottom of the vessel; and the cavity of the vessel will be almost a perfect vacuum.

6. Whenever a vacuum is made in any vessel, the air by its weight will endeavour to rush into the vessel, or to drive in any other body that will give way to its pressure; as may be easily seen by a common syringe. For, if you stop the bottom of a syringe, and then draw up the piston, if it be so tight as to drive out all the air before it, and leave a vacuum within the syringe, the piston being let go will be driven down with a great force.

7. The force with which the piston is driven down, when there is a vacuum under it, will be as the square of a diameter of the bore in the syringe. That is to say, it will be driven down with four times as much force in a syringe of a two-inch bore, as in a syringe of one inch: for the areas of circles are always as the squares of their diameters.

8. the pressure of the atmosphere being equal to 15 pounds upon a square inch, it will be almost equal to 12 pounds upon a circular inch. So that, if the bore of the syringe be round, and one inch in diameter, the piston will be pressed down into it by a force nearly equal to 12 pounds: but if the bore be two inches diameter, the piston will be pressed down with four times that force.

And hence it is easy to find with what force the atmosphere presses upon any given number either of square or circular inches.

These being the principles upon which this engine is constructed, we shall next describe the chief working parts of it: which are, 1. A boiler. 2. A cylinder and piston. 3. A beam or lever.

The *boiler* is a large vessel made of iron or copper; and commonly so big as to contain about 2000 gallons.

LECT V.

The *cylinder* is about 40 inches diameter, bored so smooth, and its leather piston fitting so close, that little or no water can get between the piston and sides of the cylinder.

Things being thus prepared, the cylinder is placed upright, and the shank of the piston is fixed to one end of the *beam*, which turns on a center like a common balance.

The boiler is placed under the cylinder, with a communication between them, which can be opened and shut occasionally.

The boiler is filled about half full of water, and a strong fire is made under it: then, if the communication between the boiler and the cylinder be opened, the cylinder will be filled with hot steam; which would drive the piston quite out at the top of it. But there is a contrivance by which the piston, when it is near the top of the cylinder, shuts the communication at the top of the boiler within.

This is no sooner shut, than another is opened, by which a little cold water is thrown upwards in a jet into the cylinder, which, mixing with the hot steam, condenses it immediately; by which means a vacuum is made in the cylinder, and the piston is pressed down by the weight of the atmosphere; and so lifts up the loaded pump-rod at the other end of the beam.

If the cylinder be 42 inches in diameter, the piston will be pressed down with a force greater than 20,000 pounds, and will consequently lift up that weight at the opposite end of the beam: and as the pump-rod with its plunger is fixed to that end, if the bore where the plunger works were 10 inches diameter, the water would be forced up through a pipe of 180 yards perpendicular height.

But, as the parts of this engine have a good deal of friction, and must work with a considerable velocity, and there is no such thing as making a perfect vacuum

in the cylinder, it is found that no more than 8 pounds of pressure must be allowed for, on every circular inch of the piston in the cylinder, that it may make about 16 strokes in a minute, about 6 feet each. LECT. V.

Where the boiler is very large, the piston will make between 20 and 25 strokes in a minute, and each stroke 7 or 8 feet; which, in a pump of 9 inches bore, will raise upwards of 300 hogsheads of water in an hour.

It is found by experience that a cylinder 40 inches diameter, will work a pump 10 inches diameter, and 100 yards long: and hence we can find the diameter and length of a pump, that can be worked by any other cylinder.

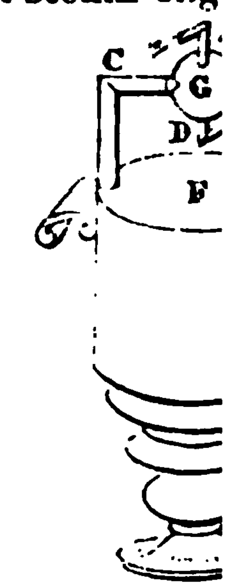
For the conveniency of those who would make use of this engine for raising water, we shall subjoin part of a table calculated by *Mr. Beighton*, shewing how any given quantity of water may be raised in an hour, from 48 to 440 hogsheads; at any given depth, from 15 to 100 yards: the machine working at the rate of 16 strokes *per* minute, and each stroke being 6 feet long.

One example of the use of this table will make the whole plain. Suppose it were required to draw 150 hogsheads *per* hour, at 90 yards depth; in the second column from the right hand, I find the nearest number, viz. 149 hogsheads 40 gallons, against which, on the right hand, I find the diameter of the bore of the pump must be 7 inches; and in the same collateral line, under the given depth 90, I find 27 inches, the diameter of the cylinder fit for that purpose.—And so for any other.

LECT. V.

Historical Account of the Steam Engine.

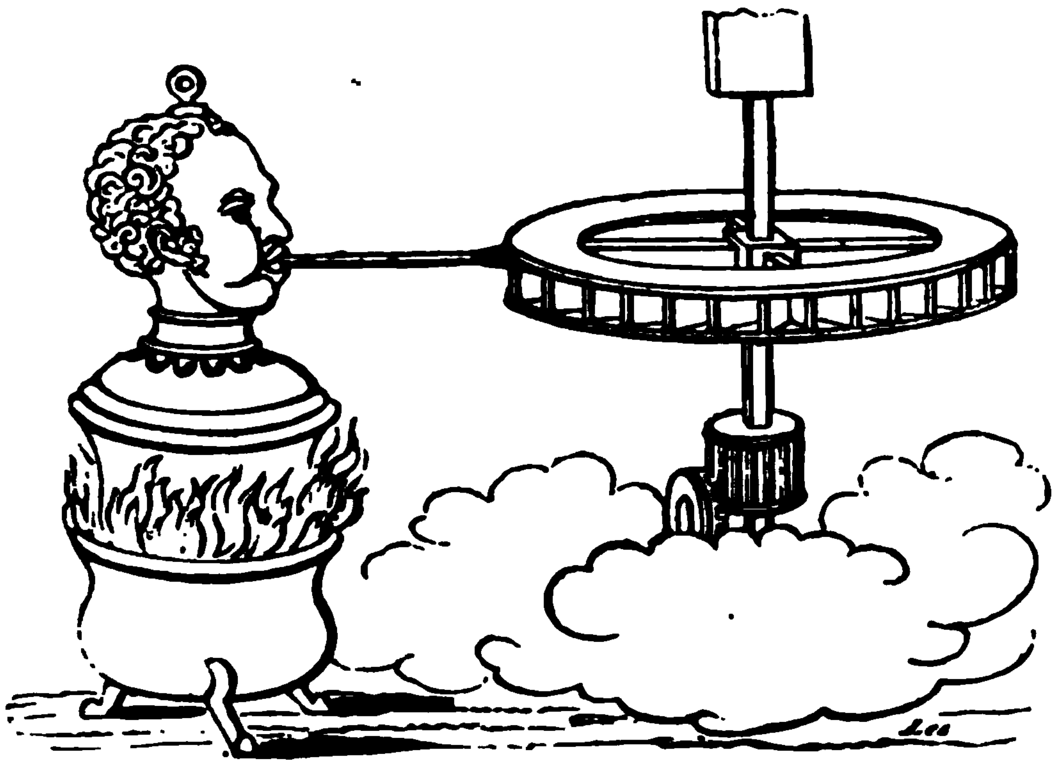
Note 48. The invention of the steam engine may ju
considered as the exclusive property of Great Britain, al
its potent labours have been productive of the happiest
in nearly every part of the civilized world. But it may l
that steam was employed as a prime mover more th
thousand years ago; and yet our country, "the first in ar
less than in arms, has scarcely possessed this stupendo
chine as a mechanical agent more than half a centur
explain this apparent inconsistency, as well as to fill
very brief sketch furnished by our Author, it may be ad
to examine the engine in its earliest form; and it will l
that neither the ingenious philosophical toys of Hero and
cas, nor the more complete apparatus for raising water su
by Savery and Newcomen, can at all be compared wi
chef d'œuvre of human ingenuity,—a modern steam eng



The apparatus suggested by Hero, consisted of a vessel *F*, in which steam was generated by the application of external heat. The ball *G* was supplied with the elastic vapour thus procured by means of the bent pipe *E B*; a steam-tight joint being provided for that purpose. Two tubes, bent to a right angle at *A* and *D*, are the only parts open to the air, and as the steam rushes out from the minute apertures, the re-action produces a rotatory motion. An account of this apparatus is preserved in Hero's *Spiritalia*, published by the
in 1693, and a copy of this highly curious work, with
translation prefixed, is now in the library of the Londo
tution.

Brancas's revolving apparatus, as will be seen by refer
the following diagram, was still more simple than that co
by Hero. A hollow copper ball filled with water, being fu
with a small tube, is seen to give motion to a float-wheel,
is impelled by the action of the elastic vapour generated
The only work in which a description of this engine h
preserved, was published in 1629. It is exceedingly ra
the above diagram is accurately copied from an engravin
possession of Major Colby

LECT. V.



A slight examination of the principle upon which this simple pparatus is constructed, will shew that no very considerable rce could have been obtained; as the steam, passing through e atmosphere in its passage to the wheel, must. to a certain ttent at least, be converted into water.

After the publication of this scheme, which it is probable was ver put in practice with any very useful effect, nearly thirty ars elapsed ere the farther consideration of this important ibject was resumed by the Marquis of Worcester.

The mode of employing steam recommended by the Marquis, d which he describes in his "Century of Inventions," to have en completely carried into effect, was entirely different from that his predecessors; and it is evident that the noble author had ceived no previous hint of Brancas's invention, as he exessly states, in another part of the above work, that he "ded not to set down any other men's inventions," and if he had any case acted on them, "to nominate likewise the inventor."

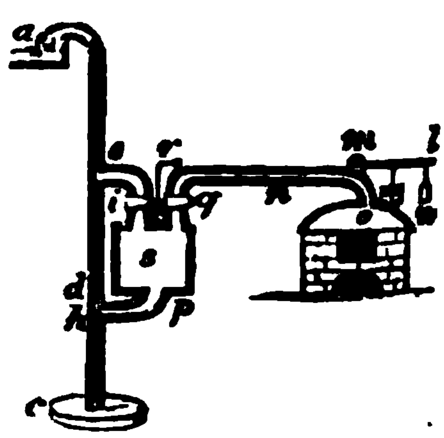
It is said that the Marquis, while confined in the Tower of ondon, was preparing some food in his apartment; and the ver having been closely fitted, was, by the expansion of the eam, suddenly forced off, and driven up the chimney. This rcumstance attracting his attention, led him to a train of ought, which terminated in this important discovery.[49]

The Marquis's account of his invention is as follows.—"An lmirable and most forcible way to drive up water by fire, not drawing or sucking it upwards, for that must be as the ilosopher calleth it, *Infra Sphæram activitatis*, which is but

Note 49. *Vide* Historical and Descriptive Account of the Steam igine, by C. F. Partington, p. 6.

LECT. V. at such a distance. But this way hath no bounder; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole, and, making a constant fire under it: within twenty-four hours it burst and made a great crack; so that, having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other. I have seen the water run like a constant fountain stream forty feet high; one vessel of water rarefied by fire driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and re-fill with cold water, and so successively, the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

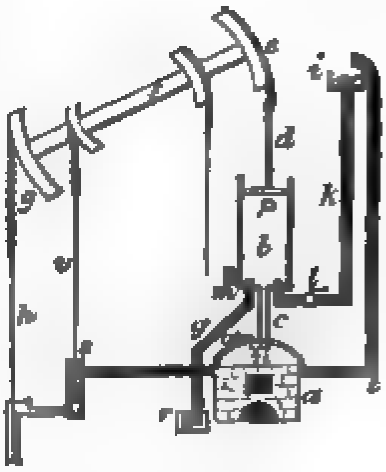
The engine suggested by Savery for the purpose of raising water, consisted of a boiler *o*, furnished with a safety-valve *m*. The steam vessel *s* was connected with the well *c* by a suction pipe *h*, and when water was to be raised, the vessel *s* was filled with steam, which, rushing in, soon expelled the air: when that was completely effected, the communication with the boiler was closed, and the steam condensed, which, diminishing its bulk, formed a vacuous space within the vessel, the pressure of the atmosphere then operating upon the surface of the water at *c*, drove it up the pipe. In this form of the apparatus, the inventor was seldom able to raise water more than thirty feet; and when a greater altitude was required, it was effected by the impellent force of the steam. This was accomplished by the ascending pipe *a d* which was sometimes carried sixty feet higher than the steam vessel *s*; and a reference to the principle by which it was effected will shew that this operation must be sometimes attended with considerable danger. After condensing the steam, and filling the vessel *s* with water, a new supply of steam was then introduced, which, pressing on the surface of the water, drove it up the pipe *d*; and it will be evident that the pressure on the internal surface of the boiler must be proportioned to the height of the column of water thus raised by the steam.



The principal objection to this form of the engine arises from

the great consumption of fuel; a considerable portion of the caloric employed in the generation of the steam being absorbed in heating the new surface of cold water last raised from the well; and where great heights are required, there appears no mode of completely obviating this objection. Should it, however, be required merely to raise water about thirty feet, there are few contrivances more economical or better adapted for general use. While speaking of Savery's apparatus, it may be advisable to notice the very ingenious adoption of the same principle to the construction of a *gas-engine* by Mr. Brown. In the latter case a vacuum is formed by the introduction of an inflamed jet of carburetted hydrogen gas, which consumes the oxygen, and rarefies the nitrogen by the increase of temperature which ensues. The vacuum thus produced is much more perfect than would at first view have been supposed from the nature of the process resorted to by the patentee, but the economy of employing hydrogen gas, as a substitute for condensible vapour, is still somewhat problematic.

The atmospheric engine will come next in order, and its claim to practical utility is much greater than either of those we have yet described. The cylinder *b* is in this case placed over a boiler *n*, and if we suppose the piston be made to fit air-tight, it will be evident that it must be driven up by the action of the steam beneath, should a sufficient supply of heat be applied; when this is effected, the condensible vapour may be reduced to its original bulk by the introduction of water from the cistern *i*.



In the working engine however, the ascent of the piston is effected by the action of the lever *e g* acting on the fulcrum *f*; to the end *g* of this lever or working beam is attached the pump rod *h*, and it will be apparent that whenever that preponderates over the piston *p*, the latter must be drawn up. On the readmission of the steam, a new supply of condensing water is introduced by turning the cock *l*, and the pressure of the atmosphere above the piston being unbalanced by any resistance beneath, the end *e* is again depressed, and the pump rod again elevated. The pipe *q* is employed to carry off the condensing water which would otherwise accumulate within the cylinder; and the small forcing pump with its rod *v s* supplies the condensing cistern *i* by the pipe *t*.

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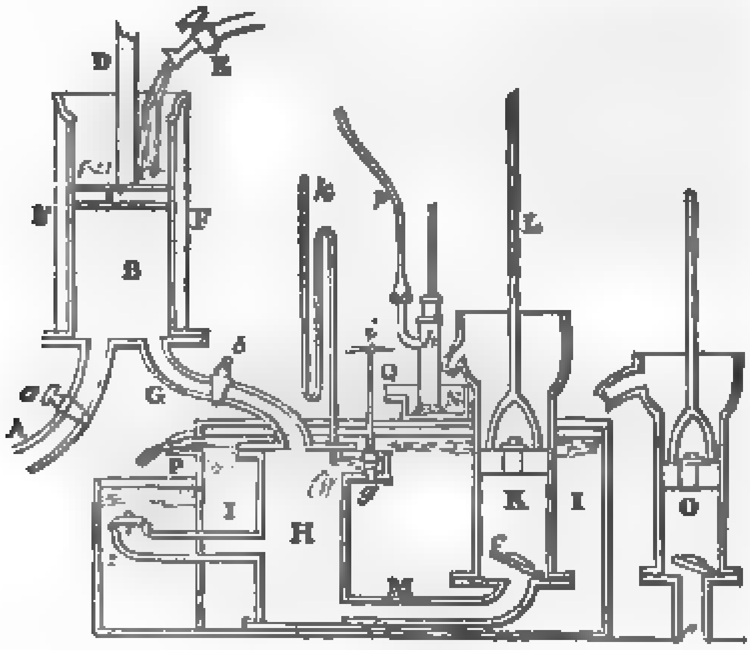
At the beginning of the last century, the atmospheric engine had made considerable progress in the mining districts, and in 1718, the patentees agreed to erect an engine for the owners of a colliery in the county of Durham, where several hundred horses had previously been employed. Mr. Henry Beighton, who was engaged as an agent in this concern, materially improved the engine by making it self-acting, and divesting it of nearly all the complicated machinery which had been previously employed for that purpose.

We come now to a new and distinct era in the history of this important invention; and in noticing the labours of Mr. Watt, we may almost speak of his engine as the gigantic offspring of a hand giving birth to an automaton no less powerful than that of the fabled enchanters of the "olden time."



The above diagram will best explain the single acting engine first invented by Mr. Watt.

A is the steam pipe connecting the boiler, in which steam is generated, with the lower part of the steam cylinder *B*, and *a* is the cock for admiting or shutting off the steam, therefore called the steam cock or valve. *C* is the piston moving in an air-tight manner upwards and downwards in the steam cylinder. *D* the piston rod, the upper end of which is connected to one end of the engine beam. *E* a cock and pipe leading to an elevated cistern, by which a little water can be discharged on the top of the piston to keep it air-tight. *FF* section of the

wooden casing or jacket, as it is technically called, that is applied round the exterior of the steam cylinder to retain the heat. It was made in separate staves, and fixed in its place by iron hoops like a barrel. *G* the eduction pipe leading from the bottom of the steam cylinder, to the upper part *H* of the condenser, which is a hollow metal vessel of any convenient form placed below the steam cylinder in a large cistern of water *I I*, called the cold water cistern; *b* a cock called the eduction valve, for opening and shutting off the connection between the steam cylinder and the condenser. *K* the air pump also fixed in the cold water cistern, but without any internal communication with the water it contains. This pump is of the common lift construction, except that its valves are of metal, on account of the heat of the water: its lower valve *c* is called the foot valve. *L* is its piston rod, the upper end of which is connected to, and works by the engine beam. *M* is its suction pipe communicating with the bottom of the condenser *H*, in order that it may draw off all the air and water it contains; and this water, being in a hot state is delivered into the smaller cistern *N*, therefore called the hot water cistern. *O* is a common pump, called the cold water pump, because it supplies cold water to the cistern *I I*, being worked by the beam, in the same manner as the air pump. The surplus cold water runs off into a drain by the spout *P*, and the hot water by another spout at *Q*.

After what has been said upon the steam engine, but little explanation can be necessary in order to understand the operation of this machine: for if the piston *C* is at the bottom of the cylinder, and the steam valve *a* be opened, steam will rush into *B*, and permit the piston to ascend in obedience to the counterpoise weights at the opposite end of the beam, until it is sufficiently raised, and at the same time the piston of the air pump will rise and produce a partial rarefaction in the condenser. So soon as the piston has got to its proper elevation, the cock *a* must be shut, and *b* opened, when the steam in the cylinder will rush into the condenser and be condensed, thereby producing such a vacuum as will cause the steam piston to descend; when *b* must be shut, and *a* opened, to produce a second rising of the piston *C*, during which the air pump *K* will draw off any condensed water that was deposited in *H*, and deliver it into *N*, thus preparing the condenser for making a second vacuum, which it is enabled to do by the cold water pump *O*, keeping the cistern *I I* constantly replenished. To increase the power of condensation, Mr. Watt found it necessary to place the cock as at *g*, for admitting a small stream of

LECT. V. water to run from the cistern into the interior of the condenser in such a direction as to meet the steam, by which the condensation was not only rendered more rapid but more perfect: this is called the injection cock.

In this state of the engine Mr. Watt found that it consumed but little more than half the fuel required by all the other constructions that had preceded it. But still he was not satisfied with the perfection of his machine; for the cylinder had an open top, and required water to lie upon the top of the piston to keep it air-tight; consequently whenever the piston descended, the whole interior surface of the cylinder was not only exposed to the open air, but was coated with a thin layer of cold water, which, by the previously acquired heat of the cylinder, was immediately converted into vapour, thus cooling it to a great degree, so that a material waste of heat still existed, which none of the before-mentioned improvements could remove. Mr. Watt therefore determined on trying the effect of a cylinder with a close top, or one which should effectually shut out the external air, by causing the rod of its piston to slide through a stuffing box, and instead of admitting the atmosphere to depress the piston, he made use of steam for that purpose, as well as to produce the vacuum. This expedient he was persuaded he could resort to, because the air's pressure could at no time exceed about 15 pounds on the square inch, and he knew that the elastic force of steam had been used to a much greater extent in Savery's engine, and could be productive of no danger, while it was kept within the moderate limits he required; for since the steam in his new machine had to act against a vacuum under the piston, instead of against the resistance of the open air, so at the heat of 212 degrees it would be fully equivalent to the pressure of the atmosphere; and by using it but a very little hotter it would even be superior to it. His only doubt therefore was, whether this additional expenditure of steam might not occasion a greater consumption of fuel than the waste that occurred through the cooling of the cylinder, but the trial of the experiment set this point at rest, and proved most clearly the value of his suggestion, and in his future engines he carried the improvement so much further, both in the single and double acting engines, as they were afterwards called, as to require no more steam for this new mode of operating, than had formerly been required to produce the vacuum only. The machine was now for the first time actually converted into a steam, instead of an atmospheric engine, for atmospheric pressure was entirely excluded, and it

y by the power of steam : in consequence of which could at all times be kept as hot as the steam which it, and all the immense loss of fuel that had hither- the use of this valuable machine was completely hile its work was rendered regular and conti-

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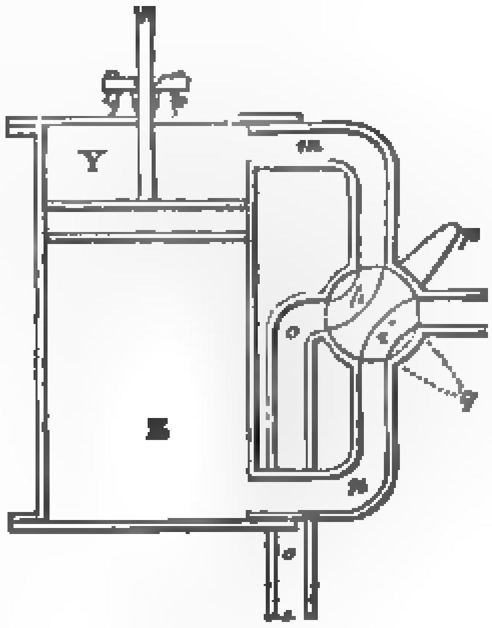
le acting engine requires twice the quantity of steam be necessary for a single engine of the same size; compensated for by its doing twice the quantity of after what has been said upon the single engine, e added in explanation of the double one, for its eing the same, a mere change of mechanism is all ired to produce the machine. No compensation necessary to raise the steam piston, and such an ust be made in the valves and steam pipes that a y be produced by the condenser, alternately above e piston, instead of below it only, as in the engines ed; the steam likewise must be admitted alternately elow the piston, at the same moment that the vacuum ut always on that side of the piston that is opposite m.

o a due comprehension of the action of the double e of the contrivances that have been adopted to pro- er distribution of the steam, and an alternate vacuum, e noticed, and although the four-way cock, and lator are not considered as the most perfect of these, very frequently applied to small steam engines, and ity gives them a preference. Let YZ represent a steam engine cy- ore, with its pis- iston rod moving uffing box, so as air-tight, g is the r bringing steam r, and this termi- four-way cock together with the nd o, are drawn rge for the cylin- order that their e distinctly seen: of a lever or han- urpose of turning



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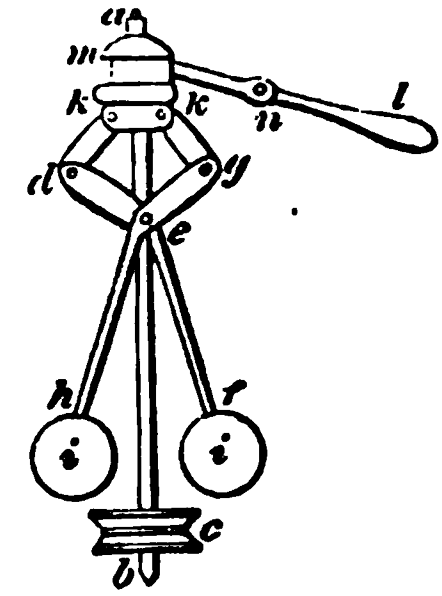
the cock when required. This cock is constructed precisely in the same manner as other cocks for fluids, and consists of a conical plug or pin ground very truly into the body of the cock itself, but instead of having a single straight passage through the plug, as is commonly the case, there are two curved ones *h* and *i*, which give the plug the appearance of having four openings, each appearing in the same plane, and at one quarter of the circumference apart, so that as the cock stands in the figure, steam coming from *g* would pass through the opening *i* in the plug, and would be delivered into the pipe *n* at right angles to its first direction, instead of passing directly onwards to *o*, as would be the case in a common cock. From the pipe *n* the steam would pass immediately into the lower part *Z* of the cylinder, and consequently would drive the piston upwards. At the same time it will be seen that there is an immediate connection between the upper part *Y* of the cylinder through the pipe *m*, and opening *h* of the cock to the pipe *o o*, leading down to the condenser; consequently, so long as the steam is acting against the under side of the piston, there will be a vacuum at *Y* to permit it to rise. So soon as the piston has arrived near the top of the cylinder, the cock must be turned one quarter round by depressing its handle *p* from its present position to that shewn by the dotted lines at *q*, by which all the openings in the plug of the cock will be changed:—steam, therefore, which now enters at *g* will be turned upwards by the passage *h*, and by entering the pipe *m* will be conveyed above instead of below the piston, while the passage *i* forms a connection between the pipe *n*, leading to the lower part of the cylinder, and the pipe *o* leading to the condenser; consequently in this position, a vacuum will be formed below the piston, while the steam is operating above it. The piston will therefore descend, and on coming near the bottom, the cock must be again turned into its first position, when the piston will ascend, and so on; thus producing an equality of force, both in the up and down strokes, by simply turning one cock, an operation that is effected by the motion of the beam without any other assistance.—Vide PROFESSOR MILLINGTON'S Lectures.

The *governor* is a very important part of the mechanism of a modern steam engine, and the simple arrangement of its parts may be readily explained by reference to the annexed diagram. A square iron rod *a b*, with pivots as its two ends, is fixed up in a vertical direction in any convenient part of the engine house, so that it can revolve on its axis in proper bearings,



and such motion is given to it either by wheel work, or by a gut-band passing round a rigger or pulley fixed upon the fly-wheel shaft, or some other revolving part of the engine, and also round the pulley *c*; and the relative velocities of the governor and the engine must be adjusted by such wheel-work, or the respective diameters of the two pulleys. Towards the upper part of the rod or spindle *a b*, two bent levers *d e f* and *g e h* are fixed, so that they can both turn or open on the common centre *e*, which is fixed to the spindle; a heavy iron ball *i i* is fixed to the end of each bent lever, and the upper ends *d* and *g* of these levers are attached by connecting links *k k*, with joints to the sliding piece *m*, which slides freely on the square spindle. It follows therefore that while the two balls *i i* lie in contact with the spindle *a b*, the slider *m* will be pushed to its greatest possible height upon the rod, but whenever the balls *i i* are opened out, the slider *m* must be depressed. The weight of the balls keeps them in contact with the spindle, so long as it remains stationary or moves slowly, but whenever their revolving motion increases, their centrifugal force will drive them to a greater or less distance from the centre: *l n* is an iron lever turning on the fixed pivot *n*, while its opposite end enters a groove formed in the sliding piece *m*; this is merely for multiplying or increasing the motion produced in *m*, when necessary; for by prolonging the distance between *n* and *l*, the end *l* may be made to move in any required degree. To apply the governor to the regulation of the velocity of the engine, it therefore only becomes necessary to connect the end *l* of the lever by means of strong wires with the lever of the throttle valve, taking care that that valve shall be quite open when the two balls of the governor are lying close to their spindle, for then the engine will move at its full speed. By so doing, the balls will instantly separate and raise the end *l* of the governor-lever, which by drawing upon the lever or the throttle valve will partly close it and diminish the speed.

The parallel motion still remains to be described, which became necessary when the double acting engine was introduced. This ingenious combination of simple levers is intended to ensure the parallelism of the piston rod, and its operation may be best understood by reference to the following figure: *p q* represents

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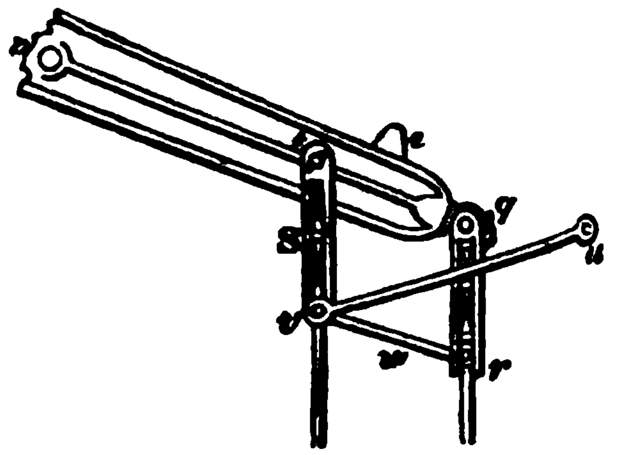
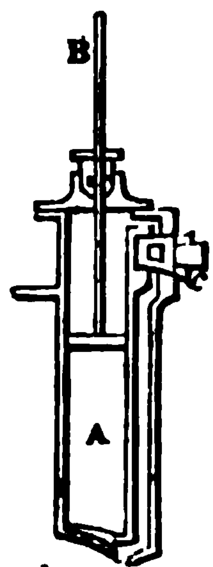


the half of a beam, p being the centre upon which it turns while the piston rod is attached to its end q, by connection at r with the lower end of the intermediate piece between q and r; in order to produce a vertical right lined motion in this piston rod, another piece s is introduced, equal in length to the first intermediate piece, and hung so as to turn upon pivots fixed to the beam between its centre and extreme end as at t; to the lower part of this second piece, the secondary beam or radius rod $v\,u$ is attached, so that it may turn upon a fixed pivot at u, while its length is equal to the distance $p\,t$, consequently it will produce a vertical rectilinear motion in the lower extremity v of the sling, or second intermediate piece s, and this is communicated back to the point r, where the piston is attached, by the bridle rod w having pivots working in the lower extremities of v and r. In this way two right lined vertical motions are produced at the points v and r whenever the beam moves, consequently, while the steam piston is attached to r, the piston rod of the air pump is generally applied to v, since they both require a perpendicular motion.

The action of the *high pressure engine*, depends upon the property of steam to expand itself, and thus acquires a very considerable elastic force by the addition of a given quantity of heat. It may indeed, be considered as a return to the principle of Brancas and the Marquis of Worcester, as in this engine no condensation is necessary, and it acts merely by the elastic or repellent force of steam.

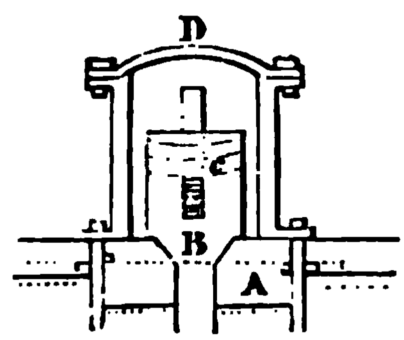
The high pressure engines constructed by Messrs. Trevithick differ but in a very small degree from the engine invented by Mr. Watt. In the high pressure engine the condenser is taken away, and the steam, instead of being converted into water by artificial cold, in a close vessel, is allowed to escape into the atmosphere from one side of the piston while it is acting forcibly on the others.

The advantages of the high pressure engine over that used with a condenser are, cheapness in construction, and a saving of the whole expence attendant on procuring a sufficient supply of condensing water, which, in some cases, is an object of considerable importance.



annexed section, the piston *B* passes through ght stuffing box; and the steam is entering it by the four-way cock *c*. If we now sup- piston at the top of the cylinder, a new nent of the communicating pipe then takes is the steam which was beneath escapes, fresh supply enters above, and an alternate and downward motion of the piston is thus d.

ever and balance-ball safety valve employed e early boilers appear but little calculated for those en- which high pressure steam is employed, as the engine- an over anxious zeal for the full performance of the machi- nfided to his care, has been frequently known to increase rnal pressure of a large boiler many thousand pounds be- resistance to which it was originally proved. To prevent ence of those accidents, which first drew the attention of lature to this important part of the engine, it appears e to inclose the safety valve in an iron case, of which a s annexed.



alve *B* in this case rests upon a seat in the boiler *A*, and is fur- vith a series of small moveable ttered *c*, which are employed to or diminish the entire weight of ty-valve, the whole being covered ox *D*; and as this is pierced with a of small holes, the steam readily escapes when the ex- force exceeds the resistance offered by the loaded valve. . Woolf's engine, high pressure steam is also employed; cylinder, or rather a pair of cylinders of unequal size. re so constructed that the steam, after it has performed e in the first cylinder, is allowed to expand into one of mensions, where it produces a vacuum by condensation. m entering above the small piston while a vacuum is beneath the large one, and vice versa.

alve of this engine may, however, be best understood, amination of its effective force, when applied to the rais- ater. A double cylinder expansion engine, was con- for Wheal Vor mine in 1815, furnished with a large of 53 inches in diameter, and making a nine-feet stroke, l cylinder being about one fifth of the size of that which loyed for the expansion of the steam. The engine was

LECT. V. constructed to work six pumps, capable of raising at each stroke a load of water equal to 37,982 pounds seven feet and a half high; and so perfect was its action, that a bushel of coals raised 46 millions of pounds one foot high.

The application of steam engines to the *propelling* of *carriages* on the public road, has hitherto been considered as a refinement in mechanics, rather to be wished for than a matter of reasonable expectation. The *locomotive* engine was first employed for this purpose by Messrs. Trevithick and Vivian, in 1802; and it found a ready introduction to the mining districts where rail roads are general. In some cases, five, six, and even ten waggons laden with coal are dragged up an inclined plane by means of these vehicles; and of course impelled by a high pressure engine, from the utter impossibility of carrying condensing water in a moveable vehicle.

An engine of four horses' power, employed by Mr. Blenkinsop, impelled a carriage lightly loaded on a rail road at the rate of ten miles an hour, and when connected with thirty coal wagons, each weighing more than three tons, its average rate was about one third of that pace.

When the locomotive engine was first tried, it was found difficult to produce a sufficient degree of re-action between the wheels and the tract road; so that the wheels turned round without propelling the vehicle. This inconvenience was, however, obviated by Mr. Blenkinsop, who when he adopted the locomotive engine, took up the common rails, on one side of the whole length of the road, and replaced them by a series of racks, or rails, furnished with large teeth. The impelling wheel of the engine was made to act in these teeth, so that it continued to work in a rack which insured a sufficient degree of re-action.

From the great weight of an ordinary *locomotive engine* as well as the construction of its wheel, it must be evident that the employment of this species of prime mover on the public roads would be in the highest degree destructive; and as such, that its use will still be partially confined to the mining districts, in which the greatest facilities are offered for its general adoption. Indeed, we find in one neighbourhood alone, and within a space of less than thirty square miles, more than eight miles of road admirably adapted for this species of conveyance; and it is a well known fact, that there are many situations in which iron rail-roads might be advantageously employed, in which it would be quite impossible to open a navigable canal. In illustration of the above fact, it may be proper to state, that a company, with a large capital,

is now forming for the express purpose of facilitating the conveyance of goods by locomotive engines.

The mode of applying the steam engine to the purposes of navigation is equally simple with its employment in our manufactures.

It is generally supposed that the *steam-boat* is of very recent invention; on the contrary, however, the possibility of employing steam as a prime mover in the propelling of vessels, was suggested as far back as the reign of Charles I.

In one of the old tracts preserved in the library of the London Institution there is a very curious representation of a steam boat, constructed by an engineer of the name of Hulls. And this individual, now so little known, was undoubtedly the first who applied a steam engine to the purpose of navigation.

To impel a vessel by this means, two paddle wheels, like those used in an under-shot water wheel, are connected by means of a long axis and crank, with the working beam of the steam engine; and if this motion is not found sufficiently rapid, a wheel and pinion are added, which, although it *decreases* the effective power of the engine, yet *increases* the velocity of the paddle wheels.

To illustrate the great advantages possessed by the steam engine, even in its rudest state, over every other species of prime mover yet enumerated, it may now be advisable to examine its effective force when employed in the working of pumps. It has been found that one hundred weight of coals burned in an engine on the old construction, would raise at least *twenty thousand cubic feet* of water twenty-four feet high; an engine with a twenty-four inch cylinder doing the work of *seventy-four horses*. An engine on Capt. Savery's plan, constructed by Mr. Keir, has been found to raise nearly *three millions* of pounds of water, and Mr. Watt's engine, upwards of *thirty millions* of pounds the same height.[51]

To the mining interests this valuable present of science to the arts has been peculiarly acceptable; as a large portion of our

Note 51. An ingenious foreigner, who lately visited England, has published an estimate of the mechanical force set in action by the steam engines of this country.

He supposes that the *great pyramid* of Egypt required for its erection the labour of more than 10,000 men for 20 years:—but if it were required again to raise the stones from the quarries, and place them at their present height, the action of the steam engines of England, which are managed at most by 36,000 men, would be sufficient to produce the same effect in 18 hours.

LECT. V. now most productive mineral districts must long ere this have been abandoned, had not the steam engine been employed as an active auxiliary in those stupendous works. In the draining of fens and marsh lands, this machine is in the highest degree valuable; and in England, particularly, it might be rendered still more generally useful. In practice it has been ascertained that an engine of six-horse power, will drain more than eight thousand acres, raising the water six feet in height; whilst the cost of an engine for this species of work, including the pumps, will not exceed seven hundred pounds. This is more than ten windmills could perform, at an annual expenditure of several hundred pounds; while, in the former case, the outgoings will not exceed one hundred and fifty pounds per annum. To the mariner also, the steam engine offers advantages of a no less important and novel nature than those which have already been described. By its use he is enabled to traverse the waters both against wind and tide, with nearly as much certainty, and, as the machinery is now constructed, with much less danger, than by the most eligible road conveyance. It too frequently, however, happens that the faults of any new invention are unjustly magnified, while its real advantages are seldom duly appreciated; and this axiom has been fully verified, in the clamour so unjustly raised against the application of the steam engine to nautical purposes. Accidents are now, however, but of rare occurrence; and it is more than probable, that the great improvements which have been made in the boiler and safety-valve, will effectually secure these parts of the engine from a recurrence of such tremendous explosions as characterised the first introduction of steam navigation. And, lastly, the political economist must hail with the most heartfelt gratification, the introduction of so able and efficient a substitute for animal labour as the steam engine. For it has been calculated that there are at least ten thousand of these machines at the present time at work in Great Britain, performing a labour more than equal to that of two hundred thousand horses, which, if fed in the ordinary way, would require above one million acres of land for subsistence; and this is capable of supplying the necessaries of life to more than fifteen hundred thousand human beings.

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This table is calculated to the measure of ale gallons, at 282 cubic inches per gallon.

Diameter of the cylinder in inches. The depth to be drawn in yards. 15	20	25	30	35	40	45	50	60	70	80	90	100	In one hour. Hogsh.	Gal.	Diam. of pump. Inches.
18¼	21¾	24	26½	28¼	30½	32¼	34¼	37¼	40	—	—	—	440		12
17	19¾	22	24¾	26¼	28	29¾	31¼	34¼	37	39½	—	—	369	83	11
15¼	18	20	22	23¾	25½	27	28¾	31½	33¾	36	38¼	40	304	48	10
14	16½	18	20	21½	23	24¼	25	28	30½	33	35	36½	247	7	9
13¼	15¼	17¼	19	20¼	21¾	23	24	26¼	28½	31	32½	35¼	221	15	8½
12¼	14¼	16¼	18½	19	20½	21½	23	25	27	29	30½	32½	195	22	8
12	14	15¼	17½	18¾	19¾	21	22	24¼	26	28	29½	31½	182	13	7¾
11	13¾	15	16½	18	19	20	21¼	23¼	25	27	28½	30¼	172	30	7½
10¾	13	14	15½	16¾	18¾	19	20½	22	24	25½	27	28½	149	40	7
10	12	13	14	15½	16¼	18	19	20	22	23	24½	26¼	128	54	6½
9¼	11	12	13	14	15½	16	17	19	20½	22	23	24½	110	1	6
	10	11	12	13	14	15	15¾	17	19	20	21	22¼	94	30	5½
		10	11	11¾	13	13¾	14	15½	16¾	18½	19¼	20¼	66	61	5
			10	10	11¼	12	13½	14	15	16	17	18¼	60	60	4½
				9	10	11	11½	12	13½	14	15	16	48	51	4

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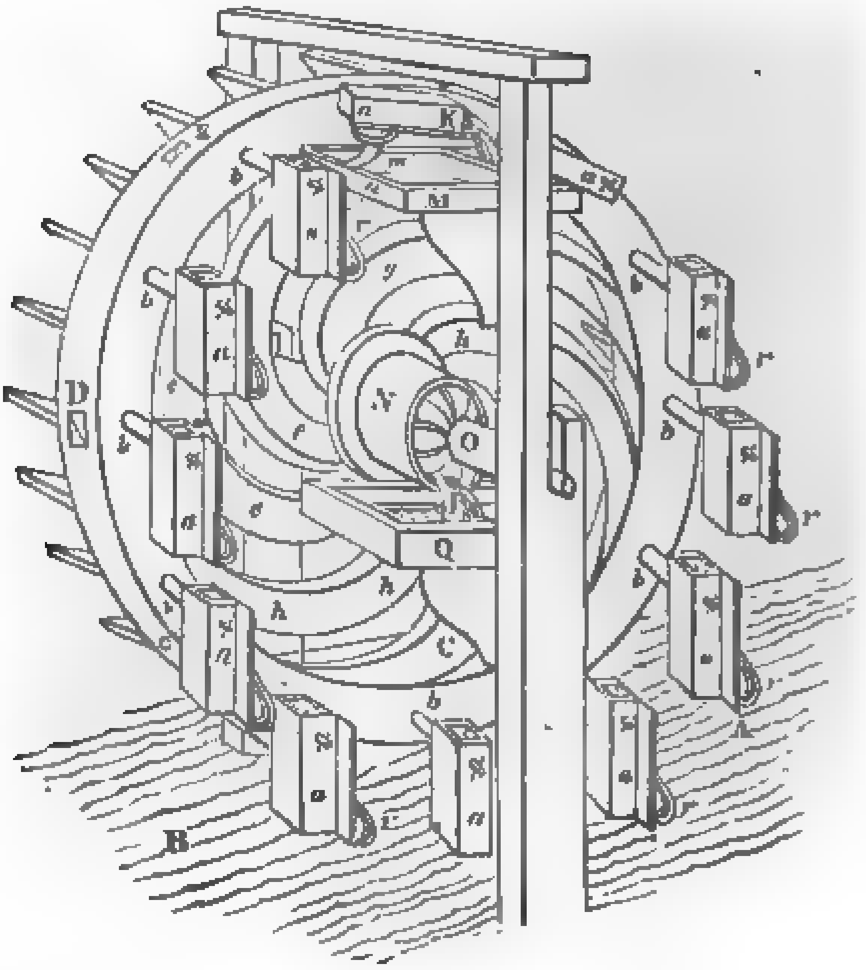
The Persian wheel.

Water may be raised by means of a stream *A B* turning a wheel *C D E*, according to the order of the



letters, with buckets *a, a, a, a,* &c. hung upon the wheel by strong pins *b, b, b, b,* &c. fixed in the side of the rim: but the wheel must be made as high as the water is intended to be raised above the level of that part of the stream in which the wheel is placed. As the wheel turns, the buckets on the right-hand go down into the water, and are thereby filled, and go up full on the left-hand, until they come to the top at *K*; where they strike against the end *n* of the fixed trough *M*, and are thereby overset, and empty the water into the trough; from which it may be conveyed in pipes to the place which it is designed for: and, as each bucket gets over the trough, it falls into a perpendicular position

again, and goes down empty, until it comes to the water at *A*, where it is filled as before. On each bucket is a spring *r*, which, going over the top or crown of the bar *m* (fixed to the trough *M*), raises the bottom of the bucket above the level of its mouth, and so causes it to empty all its water into the trough.

Sometimes this wheel is made to raise water no higher than its axle; and then, instead of buckets hung upon it, its spokes *C, d, e, f, g, h,* are made of a bent form, and hollow within; these hollows opening into the holes *C, D, E, F,* in the outside of the wheel, and also into those at *O* in the box *N* upon the axle. So that, as the holes *C, D,* &c. dip into the water, it runs into them; and as the wheel turns, the water rises in the hollow spokes, *c, d,* &c. and runs out in a stream *P* from the holes at *O*, and falls into the trough *Q*, from whence it is conveyed by pipes. And this is a very easy way of raising water, because the engine requires neither men nor horses to turn it.

Of the specific gravities of bodies.

The art of weighing different bodies in water, and thereby finding their specific gravities, or weights, bulk for bulk, was invented by ARCHIMEDES; of which we have the following account:

Hiero, king of *Syracuse*, having employed a goldsmith to make a crown, and given him a mass of pure gold for that purpose, suspected that the workman had kept back part of the gold for his own use, and made up the weight by alloying the crown with copper. But the king, not knowing how to find out the truth of that matter, referred it to *Archimedes*; who, having studied a long time in vain, found it out at last by chance. For, going into a bathing tub of water, and observing that he thereby raised the water higher in the tub than it was before, he concluded instantly that he had raised it just as high as any thing else could have done, that was exactly of his bulk: and considering

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that any other body of equal weight, and of less bulk than himself, could not have raised the water so high as he did; he immediately told the king, that he had found a method by which he could discover whether there were any cheat in the crown. For, since gold is the heaviest of all known metals, it must be of less bulk, according to its weight, than any other metal. And therefore he desired that a mass of pure gold, equally heavy with the crown when weighed in air, should be weighed against it in water; and if the crown was not alloyed, it would counterpoise the mass of gold, when they were both immersed in water, as well as as it did when they were weighed in air. But upon making the trial, he found that the mass of gold weighed much heavier in water than the crown did. And not only so, but that, when the mass and crown were immersed separately in one vessel of water, the crown raised the water much higher than the mass did; which shewed it to be alloyed with some lighter metal that increased its bulk. And so, by making trials with different metals, all equally heavy with the crown when weighed in air, he found out the quantity of alloy in the crown.

The specific gravities of bodies are as their weights, bulk for bulk; thus a body is said to have two or three times the specific gravity of another, when it contains two or three times as much matter in the same space.

A body immersed in a fluid will sink to the bottom, if it be heavier than its bulk of the fluid. If it be suspended therein, it will lose as much of what it weighed in air, as its bulk of the fluid weighs. Hence, all bodies of equal bulks, which would sink in fluids, lose equal weights when suspended therein. And unequal bodies lose in proportion to their bulks.

The *hydrostatic balance.*

The *hydrostatic balance* differs very little from a common balance that is nicely made: only it has a hook at the bottom of each scale, on which small weights may

be hung by horse-hairs, or by silk threads. So that a body, suspended by the hair or thread, may be immersed in water without wetting the scale from which it hangs.

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How to find the specific gravity of any body.

If the body thus suspended under the scale, at one end of the balance, be first counterpoised in air by weights in the opposite scale, and then immersed in water, the equilibrium will be immediately destroyed. Then, if as much weight be put into the scale from which the body hangs, as will restore the equilibrium, (without altering the weights in the opposite scale) that weight, which restores the equilibrium, will be equal to the weight of a quantity of water as big as the immersed body. And if the weight of the body in air be divided by what it loses in water, the quotient will shew how much that body is heavier than its bulk of water. Thus, if a guinea, suspended in air, be counterbalanced by 129 grains in the opposite scale of the balance; and then, upon its being immersed in water, it becomes so much lighter, as to require 7¼ grains put into the scale over it, to restore the equilibrium, it shews that a quantity of water, of equal bulk with the guinea, weighs 7 grains, or 7.25; by which divide 129 (the weight of the guinea in air), and the quotient will be 17.793; which shews that the guinea is 17.793 times as heavy as its bulk of water. And thus any piece of gold may be tried, by weighing it first in air, and then in water; and if, upon dividing the weight in air by the loss in water, the quotient comes out to be 17.793, the gold is good; if the quotient be 18, or between 18 and 19, the gold is very fine; but if it be less than 17, the gold is too much alloyed, by being mixed with some other metal.

If silver be tried in this manner, and found to be 11 times as heavy as water, it is very fine; if it be 10¼ times as heavy, it is standard; but if it be of any less weight

LECT. V compared with water, it is mixed with some lighter metal, such as tin.

By this method, the specific gravities of all bodies that will sink in water, may be found. But as to those which are lighter than water, as most sorts of wood are, the following method may be taken, to shew how much lighter they are than their respective bulks of water.

Let an upright stud be fixed into a thick flat piece of brass, and in this stud let a small lever, whose arms are equally long, turn upon a fine pin as an axis. Let the thread which hangs from the scale of the balance be tied to one end of the lever, and a thread from the body to be weighed, tied to the other end. This done, put the brass and lever into a vessel; then pour water into the vessel, and the body will rise and float upon it, and draw down the end of the balance from which it hangs: then, put as much weight in the opposite scale as will raise that end of the balance, so as to pull the body down into the water by means of the lever; and this weight in the scale will shew how much the body is lighter than its bulk of water.

There are some things which cannot be weighed in this manner, such as quicksilver, fragments of diamonds, &c. because they cannot be suspended in threads; and must therefore be put into a glass bucket, hanging by a thread from the hook of one scale, and counterpoised by weights put into the opposite scale. Thus, suppose you want to know the specific gravity of quicksilver, with respect to that of water; let the empty bucket be first counterpoised in air, and then the quicksilver put into it and weighed. Write down the weight of the bucket, and also of the quicksilver; which done, empty the bucket, and let it be immersed in water as it hangs by the thread, and counterpoised therein by weights in the opposite scale: then, pour the quicksilver into the

bucket in the water, which will cause it to preponderate; and put as much weight into the opposite scale as will restore the balance to an equipoise; and this weight will be the weight of a quantity of water equal in bulk to the quicksilver. Lastly, divide the weight of the quicksilver in air by the weight of its bulk of water, and the quotient will shew how much the quicksilver is heavier than its bulk of water.

If a piece of brass, glass, lead, or silver, be immersed and suspended in different sorts of fluids, the different losses of weight therein will shew how much it is heavier than its bulk of the fluid; the fluid being lightest in which the immersed body loses least of its aerial weight. A solid bubble of glass is generally used for finding the specific gravities of fluids.

Hence we have an easy method of finding the specific gravities both of solids and fluids, with regard to their respective bulks of common pump water, which is generally made a standard for comparing all the others by.

In constructing tables of specific gravities with accuracy, the gravity of water must be represented by unity or 1.000, where three cyphers are added, to give room for expressing the ratios of other gravities in decimal parts, as in the following table.

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A Table of the Specific Gravities of several Solid and Fluid Bodies.

A cubic inch of	Troy weight. oz.	pw.	gr.	Avoirdup. oz.	drams.	Comparative weight.
Very fine gold - -	10	7	3.83	1	5.80	19.637
Standard gold - -	9	19	6.44	10	14.90	18.888
Guinea gold - -	9	7	17.18	10	4.76	17.793
Moidore gold - -	9	0	19.84	9	14.71	17.140
Quicksilver - -	7	7	11.61	8	1.45	14.019
Lead - - - - -	5	19	17.55	6	9.08	11.325
Fine silver - - -	5	16	23.23	6	6.66	11.087
Standard silver -	5	11	3.36	5	1.54	10.535
Copper - - - -	4	13	7.04	5	1.89	8.843
Plate-brass - - -	4	4	9.60	4	10.09	8.000
Steel - - - - -	4	2	20.12	4	8.70	7.852
Iron - - - - -	4	0	15.20	4	6.77	7.645
Block tin - - -	3	17	5.68	4	3.79	7.321
Spelter - - - -	3	14	12.86	4	1.42	7.065
Lead ore - - -	3	11	17.76	3	14.96	6.800
Glass of antimony	2	15	16.89	3	0.89	5.280
German antimony	2	2	4.80	2	5.04	4.000
Copper ore - - -	2	1	11.83	2	4.43	3.775
Diamond - - -	1	15	20.88	1	15.48	3.400
Clear glass - - -	1	13	5.58	1	13.16	3.150
Lapis lazuli - -	1	12	5.27	1	12.27	3.054
Welsh asbestos -	1	10	17.57	1	10.97	2.913
White marble - -	1	8	13.41	1	9.06	2.707
Black ditto - - -	1	8	12.65	1	9.02	2.704
Rock crystal - -	1	8	1.00	1	8.61	2.658
Green glass - -	1	7	15.38	1	8.26	2.620
Cornelian stone -	1	7	1.21	1	7.73	2.568
Flint - - - - -	1	6	19.63	1	7.53	2.542
Hard paving stone	1	5	22.87	1	6.77	2.460
Live sulphur - -	1	1	2.40	1	2.52	2.000
Nitre - - - - -	1	0	1.08	1	1.59	1.900
Alabaster - - -	0	19	18.74	1	1.35	1.875
Dry ivory - - -	0	19	6.09	1	0.89	1.825
Brimstone - - -	0	18	23.76	1	0.66	1.800
Alum - - - - -	0	17	21.92	1	15.72	1.714

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The Table concluded.

A cubic inch of	Troy weight. oz. pw. gr.	Avoirdup. oz. drams.	Comparative weight.
Ebony - - - -	0 11 18.82	0 10.34	1.117
Human blood - -	0 11 2.89	0 9.76	1.054
Amber - - - -	0 10 20.79	0 9.54	1.030
Cow's milk - - -	0 10 20.79	0 9.54	1.030
Sea water - - -	0 10 20.79	0 9.54	1.030
Pump water - -	0 10 13.30	0 9.26	1.000
Spring water - -	0 10 12.94	0 9.25	0.999
Distilled water -	0 10 11.42	0 9.20	0.993
Red wine - - -	0 10 11.42	0 9.20	0.993
Oil of amber - -	0 10 7.63	0 9.06	0.978
Proof spirits - -	0 9 19.73	0 8.62	0.931
Dry oak - - -	0 9 18.00	0 8.56	0.925
Olive oil - - -	0 9 15.17	0 8.45	0.913
Pure spirits - -	0 9 3.27	0 8.02	0.866
Spirit of turpentine	0 9 2.76	0 7.99	0.864
Oil of turpentine -	0 8 8.53	0 7.33	0.772
Dry crabtree - -	0 8 1.69	0 7.08	0.765
Sassafras wood -	0 5 2.04	0 4.46	0.482
Cork - - - - -	0 2 12.77	0 2.21	0.240

Take away the decimal points from the numbers in the right-hand column, or (which is the same) multiply them by 1000, and they will shew how many ounces avoirdupoise are contained in a cubic foot of each body.

How to find out the quantity of adulteration in metals.

The use of the table of specific gravities will best appear by an example. Suppose a body to be compounded of gold and silver, and it is required to find the quantity of each metal in the compound.

First, find the specific gravity of the compound, by weighing it in air and in water, and dividing its aerial weight by what it loses thereof in water, the quotient will shew its specific gravity, or how many times it is heavier than its bulk of water. Then, subtract the specific gra-

LECT. V. vity of silver (found in the table) from that of the compound, and the specific gravity of the compound from that of gold; the first remainder shews the bulk of gold, and the latter the bulk of silver, in the whole compound: and if these remainders be multiplied by the respective specific gravities, the products will shew the proportion of weights of each metal in the body. Example.

Suppose the specific gravity of the compounded body be 13; that of standard silver, (by the table) is 10.5, and that of gold 19.63; therefore 13.5 from 13 remains 2.5, the proportional bulk of the gold; and 13 from 19.63 remains 6.63 the proportional bulk of silver in the compound. Then, the first remainder 2.5, multiplied by 19.63, the specific gravity of gold, produces 49.075 for the proportional weight of gold; and the last remainder 6.63 multiplied by 10.5, the specific gravity of silver, produces 69.615 for the proportional weight of silver in the whole body. So that for every 49.07 ounces or pounds of gold, there are 69.6 pounds or ounces of silver in the body.

Hence it is easy to know whether any suspected metal be genuine, or alloyed, or counterfeit; by finding how much it is heavier than its bulk of water, and comparing the same with the table: if they agree, the metal is good; if they differ, it is alloyed or counterfeited.

How to try spirituous liquors. A cubical inch of good brandy, rum, or other proof spirits, weighs 235.7 grains; therefore, if a true inch cube of any metal weighs 235.7 grains less in spirits than in air, it shews the spirits are proof. If it loses less of its aerial weight in spirits, they are above proof; if it loses more, they are under. For, the better the spirits are, they are the lighter; and the worse, the heavier. All bodies expand with heat and contract with cold, but some more and some less than others. And therefore the specific gravities of bodies are not precisely the same in summer as in winter. It has been found that a cubic inch of good brandy is 10 grains heavier in winter than in

summer; as much spirits of nitre, 20 grains; vinegar 6 grains, and spring-water 3. Hence it is most profitable to buy spirits in winter, and sell them in summer, since they are always bought and sold by measure. It has been found, that 32 gallons of spirits in winter will make 33 in summer.

The expansion of all fluids is proportionable to the degree of heat; that is, with a double or triple heat, a fluid will expand two or three times as much.

The thermometer.

Upon these principles depends the construction of the thermometer, in which the globe or bulb, and part of the tube, are filled with a fluid, which, when joined to the barometer, is spirits of wine tinged, that it may be more easily seen in the tube. But when thermometers are made by themselves, quicksilver is generally used.

In the thermometer, a scale is fitted to the tube, to shew the expansion of the quicksilver, and consequently the degree of heat. And, as *Fahrenheit's* scale is most in esteem at present, I shall explain the construction and graduation of thermometers, according to that scale.

First, Let the globe or bulb, and part of the tube, be filled with a fluid; then immerse the bulb in water just freezing, or snow just thawing; and even with that part in the scale where the fluid then stands in the tube, place the number 32, to denote the freezing point: then put the bulb under your arm-pit, when your body is of a moderate degree of heat, so that it may acquire the same degree of heat with your skin; and when the fluid has risen as far as it can by that heat, there place the number 97: then divide the space between these numbers into 65 equal parts, and continue those divisions both above 97 and below 32, and number them accordingly.

This may be done in any part of the world; for it is found that the freezing point is always the same in all places, and the heat of the human body differs but very

LECT. V

little; so that the thermometers made in this manner will agree with one another; and the heat of several bodies will be shewn by them, and expressed by the numbers upon the scale, thus:

Air, in severe cold weather, in our climate, from 15 to 25. Air in winter, from 26 to 42. Air in spring and autumn, from 43 to 53. Air at midsummer, from 65 to 68. Extreme heat of the summer sun, from 86 to 100. Butter just melting, 95. Alcohol boils with 174 or 175. Brandy with 190. Water 212. Oil of turpentine 250. Tin melts with 408, and lead with 540. Milk freezes about 30, vinegar, 28, and blood 27.[51]

A body specifically lighter than a fluid will swim upon its surface, in such a manner, that a quantity of the fluid equal in bulk with the immersed part of the body, will be as heavy as the whole body. Hence, the lighter a fluid is, the deeper a body will sink in it; upon which depends the construction of the *hydrometer* or water-poise.[52]

Note 51. A very simple and yet delicate mode of constructing a thermometer may now be noticed. If a glass bulb be furnished with a tube, and inverted in a vessel of coloured water, the most minute augmentation in the temperature of the atmosphere will be observable. To effect this, it is merely necessary to expel a portion of the air by external heat, and as the bulb afterwards cools, it will rise in the tube; to which a scale may be attached in the ordinary way. A still more delicate mode of constructing the air thermometer, consists in substituting hydrogen gas for atmospheric air, as the former is by far the most dilatable.

Note 52. As our Author has omitted to describe this instrument, which is now so commonly employed in the science of hydrostatics, it may be advisable to examine the construction of it with sufficient minuteness to enable the general reader to understand it. The hydrometer consists of a hollow ball, furnished with a small hollow sphere, screwed beneath, partly filled with mercury or small shot, in order to render it but little specifically lighter than water. The larger ball has also a short neck, into which is screwed a graduated brass wire, which, by a small weight, causes the body of the instrument to descend in the fluid with part of the stem.

When this instrument is swimming in any liquor, the part of the

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From this we can easily find the weight of a ship, or any other body that floats in water. For, if we mul-

How the weight of a ship in water may be estimated.

fluid displaced by it, will be equal in bulk to the part of the instrument under water, and equal in weight to the whole instrument. Now, suppose the weight of the whole to be 4000 grains, it is evident we can by this means compare the different dimensions of 4000 grains of several sorts of fluids. For if the weight on the top be such as will cause the ball to sink in rain-water, until its surface come to the middle point of the stem; and after that, if it be immersed in common spring-water, and the surface be observed to stand at one-tenth of an inch below the middle point, it is apparent that the same weight of each water differs only in bulk, by the magnitude of one-tenth of an inch in the stem.

Now, if we suppose the stem to be ten inches long, and weigh 100 grains, then every tenth of an inch will weigh one grain; and as the stem is of brass, which is about eight times heavier than water, the same bulk of water will be equal to one-eighth of a grain, and consequently to one-eighth of $\frac{1}{4000}$th part; that is, $\frac{1}{32000}$th part of the whole bulk. This instrument is capable of still greater precision, by making the stem or neck consist of a flat thin slip of brass, instead of one that is cylindrical; for, by this means we increase the surface, which is the most requisite circumstance, and diminish the solidity, which necessarily renders the instrument still more accurate.

To adapt this instrument to all purposes, there should be two stems to screw on and off. One stem should be a smooth thin slip of brass, or rather steel, like a watch-spring set straight; on one side of which are to be the several marks or divisions, to which it will sink in different sorts of water; as rain, river, spring, sea, and salt spring waters, &c. and on the other side you may mark the divisions to which it sinks in various lighter fluids; as hot Bath-water, Bristol-water, Lincomb-water, Cheltenham-water, Port-wine, Mountain, Madeira, and other sorts of wines. But here the weight on the top must be a little less than before, when it was used for heavier waters.

In trying the strength of the spirituous liquors, a common cylindrical stem will do best, because of its strength and steadiness: and this ought to be so contrived, that, when immersed in what is called proof-spirit, the surface of the spirit may be upon the middle point; which is easily done by duly adjusting a small weight on the top, and making the stem of such a length, that, when immersed in water, it may just cover the ball, but when immersed in pure spirit, it may rise to the top. Then, by dividing the upper and lower parts into ten equal parts each, when the instrument is immersed in any sort of spirituous liquor, it will immediately shew how much it is above or below proof.

LECT. V. tiply the number of cubic feet which are under the surface, by 62.5, the number of pounds in one foot of fresh water; or by 64.4, the number of pounds in a foot of salt water; the product will be the weight of the ship, and all that is in it. For, since it is the weight of the ship that displaces the water, it must continue to sink until it has removed as much water as is equal to it in weight; and therefore the part immersed must be equal in bulk to such a portion of the water as is equal to the weight of the whole ship.[53]

To prove this by experiment, let a ball of some light wood, such as fir or pear-tree, be put into water contained in a glass vessel; and let the vessel be put into a scale at one end of a balance, and counterpoised by weights in the opposite scale: then, marking the height of the water in the vessel, take out the ball; and fill up the vessel with water to the same height that it stood at when the ball was in it; and the same weight will counterpoise it as before.

From the vessel's being filled up to the same height at which the water stood when the ball was in it, it is evident that the quantity poured in is equal in magnitude to the immersed part of the ball; and from the same weight counterpoising, it is plain that the water poured in, is equal in weight to the whole ball.

In troy weight, 24 grains make a pennyweight, 20 pennyweights make an ounce, and 12 ounces a pound. In avoirdupoise weight, 16 drams make an ounce, and 16 ounces a pound. The troy pound contains 5760

Note 53. A reference to the difference between the specific gravity of *salt* and *fresh* water will account for the curious fact of a vessel floating higher in salt water than in fresh. The greater buoyancy of the former enabling it to support a body higher in the water: so that if a vessel receives its cargo at a salt-water port, it will be necessary to make a certain allowance in the freight, should it afterwards be removed to river water, the specific gravity of which is, as our Author has shewn, less.

grains, and the avoirdupoise pound 7000; and hence, the avoirdupoise dram weighs 27.34375 grains, and the avoirdupoise ounce 437.5. LECT. V.

Because it is often of use to know how much any given quantity of goods in troy weight do make in avoirdupoise weight, and the reverse, we shall here annex two tables for converting these weights into one another. Those from page 147 to page 158 are near enough for common hydraulic purposes; but the two following are better, where accuracy is required in comparing the weights with one another: and I find by trial, that 175 troy ounces are precisely equal to 192 avoirdupoise ounces, and 175 troy pounds are equal to 144 avoirdupoise. And although there are several lesser integral numbers, which come very near to agree together, yet I have found none less than the above to agree exactly. Indeed 41 troy ounces are so nearly equal to 45 avoirdupoise ounces, that the latter contains only 7½ grains more than the former: and 45 troy pounds weigh only 7½ drams more than 37 avoirdupoise.

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A Table for reducing Troy Weight into Avoirdu[pois] Weight.

Troy weight.	Avoirdupoise. lb.	oz.	drams.	Troy weight.	A… D…
Pounds—4000	3291	6	13.68	Pennywt. 19	1
3000	2528	9	2.26	18	1
2000	1645	11	6.84	17	1
1000	822	13	11.42	16	1
900	740	9	2.28	15	1
800	658	4	9.14	14	1
700	576	0	0.00	[illegible]	1
600	493	11	6.85	12	[illegible]
500	411	6	13.71	11	[illegible]
400	329	2	4.57	[illegible]	[illegible]
[illegible]	246	13	11.42	9	[illegible]
200	164	9	2.28	8	[illegible]
100	82	4	9.15	7	[illegible]
90	74	0	13.62	6	[illegible]
80	65	13	4.11	5	[illegible]
70	57	9	9.60	[illegible]	[illegible]
60	49	5	15.08	[illegible]	[illegible]
50	41	2	4.57	2	
40	32	14	10.05	1	
30	24	10	15.54	Grains — 23	
20	16	7	5.03	22	
10	8	3	10.52	21	
9	7	6	7.86	20	
8	6	9	5.21	19	
7	5	12	2.56	18	
6	4	14	15.90	17	
5	4	1	13.25	16	
4	3	4	10.60	15	
3	2	7	7.95	14	
2	1	10	5.30	13	
1		13	2.65	12	
Ounces — 11		12	1.09	11	
10		10	15.54	10	
9		9	13.99	9	
8		8	12.43	8	
7		7	10.88	7	
6		6	9.32	6	
5		5	7.77	5	
4		4	6.22	4	
3		3	4.66	3	
2		2	3.11	2	
1		1	1.55	1	

ble for reducing Avoirdupoise Weight into Troy Weight.

lupoise ght.	Troy weight.				Avoird. Weight.	Troy weight.			
	lb.	oz.	pw.	gr.		lb.	oz.	pw.	gr.
6000	7291	8	0	0	Ounces 15	1	1	13	10.50
5000	6076	4	13	8	14	1	0	15	5
4000	4861	1	6	16	13		11	16	23.50
3000	3645	10	0	0	12		10	18	18
2000	2430	6	13	8	11		10	0	12.50
1000	1215	3	6	16	10		9	2	7
900	1093	9	0	0	9		8	4	1.50
800	972	2	13	8	8		7	5	20
700	850	8	6	16	7		6	7	14.50
600	729	2	0	0	6		5	9	9
500	607	7	13	8	5		4	11	8.50
400	486	1	6	16	4		3	12	22
300	364	7	0	0	3		2	14	16.50
200	243	0	13	8	2		1	16	11
100	121	6	6	16	1		0	18	5.50
90	109	4	10	0	Drams 15			17	2.10
80	97	2	13	8	14			15	22.76
70	85	0	16	16	13			14	19.42
60	72	11	0	0	12			13	15.08
50	60	9	3	8	11			12	12.74
40	48	7	6	16	10			11	9.40
30	36	5	10	0	9			10	6.06
20	24	3	13	8	8			9	2.72
10	12	1	16	16	7			8	23.38
9	10	11	5	0	6			7	20.04
8	9	8	13	8	5			6	16.70
7	8	6	1	16	4			5	13.36
6	7	3	10	0	3			3	10.02
5	6	0	18	8	2			2	6.68
4	4	10	6	16	1			1	3.34
3	3	7	15	0	$\frac{3}{4}$			0	20.51
2	2	5	3	8	$\frac{1}{2}$				13.67
1	1	2	11	16	$\frac{1}{4}$				6.83

:wo following examples will be sufficient to ex- ese two tables, and shew their agreement.

. *In* 6835 *pounds* 6 *ounces* 9 *pennyweights* 6 *Troy, Qu. How much Avoirdupoise weight?* (See 12.)

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		Avoirdupoise		
		lb.	oz.	drams.
Pounds troy—	4000	3291	6	13.68
	2000	1645	11	6.84
	800	658	4	9.14
	20	16	7	5.03
	10	8	3	10.52
	5	4	1	13.25
oz.	6		6	9.32
pw.	9			7.90
gr.	6			.22
Answer.		5624	10	11.90

Ex. II. *In 5624 pounds 10 ounces 12 drams Avoirdupoise, Qu. How much Troy weight?* (See page 193.)

		Troy.			
		lb.	oz.	pw.	gr.
Pounds avoird.	5000	6076	4	13	8
	600	729	2	0	0
	20	24	3	13	8
	4	4	10	6	16
oz.	10		9	2	7
dr.	12			13	15.08
Answer.		6835	6	9	6.08

LECTURE VI.

OF PNEUMATICS.

THIS science treats of the nature, weight, pressure, and spring of the air, and the effects arising therefrom.

The air is that thin, transparent, fluid body in which we live and breathe. It encompasses the whole earth to a considerable height; and, together with the clouds and vapours that float in it, is called the atmosphere. The air is justly reckoned among the number of fluids, because it has all the properties by which a fluid is distinguished. For, it yields to the least force impressed, its parts are easily moved among one another, it presses according to its perpendicular height, and its pressure is every way equal. The properties of air.

That the air is a fluid, consisting of such particles as have no cohesion betwixt them, but easily glide over one another, and yield to the slightest impression, appears from that ease and freedom with which animals breathe in it, and move through it without any difficulty or sensible resistance.

But it differs from all other fluids in the four following particulars.—1. It can be compressed into a much less space than what it naturally possesses, which no other fluid can. 2. It cannot be congealed or fixed, as other fluids may. 3. It is of a different density in every part, upward from the earth's surface, decreasing in its weight, bulk for bulk, the higher it rises; and therefore must also decrease in density. 4. It is of an elastic or springy nature, and the force of its spring is equal to its weight.

LECT. VI. That air is a body, is evident from its excluding all other bodies out of the space it possesses: for, if a glass jar be plunged with its mouth downward into a vessel of water, there will but very little water get into the jar, because the air of which it is full keeps the water out.

As air is a body, it must needs have gravity or weight: and that it is weighty, is demonstrated by experiment. For, let the air be taken out of a vessel by means of the air-pump: then, having weighed the vessel, let in the air again, and, upon weighing it when re-filled with air, it will be found considerably heavier. Thus, a bottle that holds a wine quart, being emptied of air and weighed, is found to be about 16 grains lighter than when the air is let into into it again; which shews that a quart of air weighs 17 grains. But a quart of water weighs 14621 grains; this divided by 16, quotes 914 in round numbers; which shews, that water is 914 times as heavy as air near the surface of the earth.

As the air rises above the earth's surface, it grows rarer, and consequently lighter, bulk for bulk. For, because it is of an elastic or springy nature, and its lowermost parts are pressed with the weight of all that is above them, it is plain that the air must be more dense or compact at the earth's surface, than at any height above it; and gradually rarer the higher up. For, the density of the air is always as the force that compresseth it; and therefore, the air towards the upper parts of the atmosphere being less pressed than that which is near the earth, it will expand itself, and thereby become thinner than at the earth's surface.

Dr. Cotes has demonstrated, that if altitudes in the air be taken in arithmetical proportion, the rarity of the air will be in geometrical proportion. For instance,

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At the altitude of	Miles above the surface of the earth, the air is	times thinner and lighter than at the earth's surface.
7		4
14		16
21		64
28		256
35		1024
42		4096
49		16384
56		65536
63		262144
70		1048576
77		4194304
84		16777216
91		67108864
98		268435456
105		1073741824
112		4294967296
119		17179869184
126		68719476736
133		274877906944
140		1099511627776

And hence it is easy to prove by calculation, that a cubic inch of such air as we breathe, would be so much rarefied at the altitude of 500 miles, that it would fill a sphere equal in diameter to the orbit of Saturn.

The weight or pressure of the air is exactly determined by the following experiment.

The Torricellian experiment.

Take a glass tube about three feet long, and open at one end; fill it with quicksilver, and, putting your finger upon the open end, turn that end downward, and immerse it into a small vessel of quicksilver, without letting in any air: then take away your finger; and the quicksilver will remain suspended in the tube 29½ inches above its surface in the vessel; sometimes more, and at other times less, as the weight of the air is varied by winds and other causes. That the quicksilver is kept up in the tube by the pressure of the

atmosphere upon that in the bason, is evident; for, if the bason and tube be put under a glass, and the air be then taken out of the glass, all the quicksilver in the tube will fall down into the bason; and if the air be let in again, the quicksilver will rise to the same height as before. Therefore, the air's pressure on the surface of the earth, is equal to the weight of 29½ inches depth of quicksilver all over the earth's surface, at a mean rate.

A square column of quicksilver, 29½ inches high, and one inch thick, weighs just 15 pounds, which is equal to the pressure of air upon every square inch of the earth's surface; and 144 times as much, or 2160 pounds upon every square foot; because a square foot contains 144 square inches. At this rate, a middle-sized man, whose surface may be about 14 square feet, sustains a pressure of 30,240 pounds, when the air is of a mean gravity: a pressure which would be insupportable, and even fatal to us, were it not equal on every part, and counterbalanced by the spring of the air within us, which is diffused through the whole body; and reacts with an equal force against the outward pressure.

Now, since the earth's surface contains (in round numbers) 200,000,000 square miles, and every square mile, 27,878,400 square feet, there must be 5,575,680,000, millions of square feet on the earth's surface; which multiplied by 2160 pounds (the pressure on each square foot, gives 12,043,468,800,000,000,000 pounds for the pressure or weight of the whole atmosphere.

When the end of a pipe is immersed in water, and the air is taken out of the pipe, the water will rise in it to the height of 33 feet above the surface of the water in which it is immersed; but will go no higher: for it is found, that a common pump will draw water no higher than 33 feet above the surface of the well: and unless the bucket goes within that distance from the well the water will never get above it. Now, as it is

the pressure on the surface of the water in the well, that causes the water to ascend in the pump, and follow the piston or bucket, when the air above it is lifted up; it is evident, that a column of water, 33 feet high, is equal in weight to a column of quicksilver of the same diameter 29½ inches high; and to as thick a column of air, reaching from the earth's surface to the top of the atmosphere.

The *barometer*

In serene calm weather, the air has weight enough to support a column of quicksilver 31 inches high; but, in tempestuous stormy weather, not above 28 inches. The quicksilver, thus supported in a glass tube, is found to be a nice counterbalance to the weight or pressure of the air, and to shew its alterations at different times. And being now generally used to denote the changes in the weight of the air, and of the weather consequent upon them, it is called the *barometer*, or weather-glass.

The pressure of the air being equal on all sides of a body exposed to it, the softest bodies sustain this pressure without suffering any change in their figure; and so do the most brittle bodies without being broken.

The cause of *winds*.

The air is rarefied, or made to swell with heat; and of this property, *wind* is a necessary consequence. For, when any part of the air is heated by the sun, or otherwise, it will swell, and thereby affect the adjacent air: and so, by various degrees of heat in different places, there will arise various winds.

When the air is much heated, it will ascend towards the upper part of the atmosphere, and the adjacent air will rush in to supply its place; and therefore, there will be a stream or current of air from all parts towards the place where the heat is. And hence we see the reason why the air rushes with such force into a glass-house, or towards any place where a great fire is made. And also, why smoke is carried up a chimney, and why the air rushes

LECT. VI.

in at the key-hole of the door, or any small chink, when there is a fire in the room. So we may take it in general, that the air will press towards that part of the world where it is most heated.

The *trade-winds.*

Upon this principle, we can easily account for the *trade-winds,* which blow constantly from east to west about the equator. For, when the sun shines perpendicularly on any part of the earth, it will heat the air very much in that part, which air will therefore rise upward, and when the sun withdraws, the adjacent air will rush in to fill its place; and consequently will cause a stream or current of air from all parts towards that which is most heated by the sun. But as the sun, with respect to the earth, moves from east to west, the common course of the air will be that way too; continually pressing after the sun: and therefore, at the equator, where the sun shines strongly, there will be a continual wind from the east; but, on the north side, it will incline a little to the north, and on the south-side, to the south.

This general course of the wind about the equator, is changed in several places, and upon several accounts; as, 1. By exhalations that rise out of the earth at certain times, and from certain places; in earthquakes, and from volcanos. 2. By the falling of great quantities of rain, causing thereby a sudden condensation or contraction of the air. 3. By burning sands, that often retain the solar heat to a degree incredible to those who have not felt it, causing a more than ordinary rarefaction of the air contiguous to them. 4. By high mountains, which alter the direction of the winds in striking against them. 5. By the declination of the sun towards the north or south, heating the air on the north or south side of the equator.

To these and such like causes is owing, 1. the irregularity and uncertainty of winds in climates distant from the equator, as in most parts of Europe. 2. Those

winds, called *monsoons*, which in the Indian half a year one way, and the other half ano- Those winds which on the coast of Guinea, ıe western coasts of America, blow always to east. 4. The sea-breezes, which, in hot blow generally from sea to land, in the day- the land-breezes, which blow in the night; ıort, all those storms, hurricanes, whirlwinds, ılarities, which happen at different times and

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The *monsoons.*

Our Author has here omitted the *Sirocco,*

> "Whose widely wasting breath
> The very cypress dooms to death."

ıf this pestilential air is represented as resembling burning ıe mouth of an oven: the whole atmosphere, during its con- ns to be in a flame. Its effect is described by Brydone like f the subterranean sweating stoves at Naples; but it was In a few minutes, those who are exposed to it find every in a most inconceivable manner, and the pores opened to e, that they expect immediately to be thrown into a most t. At this time the thermometer, which stood in a room se immediately in the open air to 110, and soon after to 112. hick and heavy, but the barometer was little affected, having bout a line. The sun did not appear during the whole se the heat, says Mr. Brydone, must have been insupport- that side that was exposed to the wind, it could not be t difficulty for a few minutes. Upon exposing pomatum to ' the wind melted it as if it had been laid before the fire. more or less violent, and of longer or shorter duration at s; however, it seldom lasts more than 36 or 40 hours, so ı of the houses are not warmed throughout, or else it is ap- ıat it would be insupportable. Whilst it lasts, the people y confine themselves within; their windows and doors are prevent the external air from entering; and where window- wanting, they hang up wet blankets on the inside of the he servants are constantly employed in sprinkling water he apartments, in order to preserve the air in as temperate a ble; and for this purpose, each house in the city of Palermo rith a fountain. By these means the people of fashion suffer om this wind, except the strict confinement to which it Notwithstanding the scorching heat of the sirocco, it has known to produce any epidemical disorders, or to do any

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The *vivifying spirit* in air.

All common air is impregnated with a certain kind of *vivifying spirit* or quality, which is necessary to continue the lives of animals: and this, in a gallon of air, is sufficient for one man during the space of a minute, and not much longer.[55]

This spirit in air is destroyed by passing through the lungs of animals: and hence it is, that an animal dies soon after being put under a vessel which admits no fresh air to come to it. This spirit is also in the air which is in water: for fish die when they are excluded from fresh air, as in a pond that is closely frozen over. And the little eggs of insects, stopped up in a glass, do not produce their young, though assisted by a kindly warmth. The seeds also of plants mixed with good earth, and inclosed in a glass, will not grow.

injury to the health of the people. They feel, indeed, very weak and relaxed after it; but a few hours of the Tramontane or north wind, which generally succeeds it, soon braces them up again, and restores them to their former state. However, in Naples, and some other parts of Italy, where its violence is not to be compared with that of Palermo, it is often attended with putrid disorders, and seldom fails to produce almost a general dejection of spirits. But there the sirocco lasts for many days, and even for weeks; so that, as its effects are different, it probably proceeds from a different cause. Some have supposed that this is the same wind with that which is so dreadful in the sandy desarts of Africa, where it sometimes proves mortal in the space of half an hour; but that in its passage over the sea, it is cooled and deprived of its tremendous influence, before it reaches Sicily. If this were true, we might expect to find it most violent on that side of the island that lies nearest to Africa, which is not the case; though it is possible, that its heat may be again increased by its passage across the island to Palermo, near the most northern part: and besides, this city is almost surrounded by very high mountains, the ravines and valleys betwixt which are entirely parched up and burning hot at this summer season of the year. These likewise contain springs of warm water, the steams of which may increase the heat, and at the same time soften the air, so as to disarm it of its noxious qualities.

Note 55. The *vivifying spirit* here alluded to, is essential to combustion, no less than to animal life; and this important constituent of our atmosphere is now better known by the term *oxygen*. It is a gaseous fluid, and forms about one fourth of the air that surrounds us.

This enlivening quality in air, is also destroyed by the air's passing through fire; particularly charcoal fire, or the flame of sulphur. Hence, smoking chimneys must be very unwholesome, especially if the rooms they are in be small and close. LECT. VI.

Air is also vitiated, by remaining closely pent up in any place for a considerable time; or perhaps, by being mixed with malignant steams and particles flowing from the neighbouring bodies; or lastly, by the corruption of the vivifying spirit; as in the holds of ships, in oil-cisterns, or wine-cellars, which have been shut for a considerable time. The air in many of them is sometimes so much vitiated, as to be immediate death to any animal that comes into it.

Air that has lost its vivifying spirit, is called *damp*, not only because it is filled with humid or moist vapours, but because it deadens fire, extinguishes flame, and destroys life. The dreadful effects of damps are sufficiently known to such as work in mines.[56] *Damps.*

If part of the vivifying spirit of air in any country begins to putrify, the inhabitants of that country will be subject to an epidemical disease, which will continue until the putrefaction is over. And as the putrefying spirit occasions the disease, so if the diseased body contributes towards the putrefying of the air, then the disease will not only be epidemical, but pestilential and contagious.

The atmosphere is the common receptacle of all the effluvia or vapours arising from different bodies; of the steams and smoke of things burnt or melted; the fogs or vapours proceeding from damp watery places;

Note 56. We have stated that atmospheric air is a compound fluid, and one of its constituents is in the preceding page not unaptly called a vivifying spirit, but by far the largest portion of the air we breathe is destructive both of animal life and flame. The latter constituent is called *nitrogen;* and, in general, when we speak of an impure atmosphere, we mean one exhausted of its vivifying principle.

LECT. VI. and of the effluvia from sulphureous, nitrous, acid, and alkaline bodies. In short, whatever may be called volatile, rises in the air to greater or less heights, according to its specific gravity.

Fermentations. When the effluvia which arise from acid and alkaline bodies, meet each other in the air, there will be a strong conflict or *fermentation* between them: which will sometimes be so great, as to produce a fire: then if the effluvia be combustible, the fire will run from one part to another, just as the inflammable matter happens to lie.

Any one may be convinced of this, by mixing an acid and an alkaline fluid together, as the spirit of nitre and oil of cloves; upon the doing of which, a sudden ferment, with a fine flame, will arise; and if the ingredients be very pure and strong, there will be a sudden explosion.

Thunder and lightning. Whoever considers the effects of fermentation, cannot be at a loss to account for the dreadful effects of *thunder* and *lightning*: for the effluvia of sulphureous and nitrous bodies, and others that may rise into the atmosphere, will ferment with each other, and take fire very often of themselves; sometimes by the assistance of the sun's heat.

If the inflammable matter be thin and light, it will rise to the upper part of the atmosphere, where it will flash without doing any harm: but if it be dense, it will lie near the surface of the earth, where taking fire, it will explode with a surprising force; and by its heat rarefy and drive away the air, kill men and cattle, split trees, walls, rocks, &c. and be accompanied with terrible claps of thunder.

The heat of lightning appears to be quite different from that of other fires; for it has been known to run through wood, leather, cloth, &c. without hurting them, while it has broken and melted iron, steel, silver, gold, and other hard bodies. Thus it has melted or burned asunder a sword, without hurting the scabbard; and

money in a man's pocket without hurting his clothes: the reason of this seems to be, that the particles of *that* fire are so fine, as to pass through soft loose bodies without dissolving them; whilst they spend their whole force upon the hard ones. LECT. VI.

It is remarkable, that knives and forks which have been struck with lightning have a very strong magnetical virtue for several years after; and I have heard that lightning striking upon the mariner's compass, will sometimes turn it round; and often make it stand the contrary way, or with the north pole towards the south.[57]

Fire-damps.

Much of the same kind with lightning, are those explosions, called *fulminating* or *fire-damps*, which sometimes happen in mines; and are occasioned by sulphureous and nitrous, or rather oleaginous particles, rising from the mine, and mixing with the air, where they will take fire by the lights which the workmen are obliged to make use of. The fire being kindled will run from one part of the mine to another, like a train of gunpowder, as the combustible matter happens to lie. And as the elasticity of the air is increased by heat, *that* in the mine will consequently swell very much, and so, for want of room, will explode with a greater or less degree of force, according to the density of the combustible vapours. It is sometimes so strong as to blow up the mine; and at other times so weak, that when it has taken fire at the flame of a candle, it is easily blown out.

Air that will take fire at the flame of a candle may be produced thus. Having exhausted a receiver of the air-

Note 57. The power of communicating magnetism to ferruginous bodies by the agency of electricity has long been known; but the most remarkable effects yet exhibited were produced by a powerful galvanic apparatus, constructed under the direction of W. H. Pepys, Esq. In the experiments performed with this apparatus, a compass-needle, placed more than ten feet from the galvanic coil, was sensibly deflected from its ordinary direction, and polarity was communicated to bars of steel, which thus became permanent magnets

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pump, let the air run into it through the flame of the o of turpentine; then remove the cover of the receive and holding a candle to that air, it will take fire, an burn quicker or slower, according to the density of th oleaginous vapour.

Earthquakes.

When such combustible matter, as is above-mentioned, kindles in the bowels of the earth, where there is little or no vent, it produces *earthquakes*, and violent storms or hurricanes of wind when it breaks forth into the air.

An artificial earthquake may be made thus. Take 10 or 15 pounds of sulphur, and as much of the filings of iron, and knead them with common water into the consistence of a paste: this being buried in the ground, will, in 8 or 10 hours' time, burst out in flames, and cause the earth to tremble all round to a considerable distance.

From this experiment we have a very natural account of the fires of mount *Ætna, Vesuvius,* and other volcanos, they being probably set on fire at first by the mixture of such metalline and sulphureous particles.[58]

The air-pump.

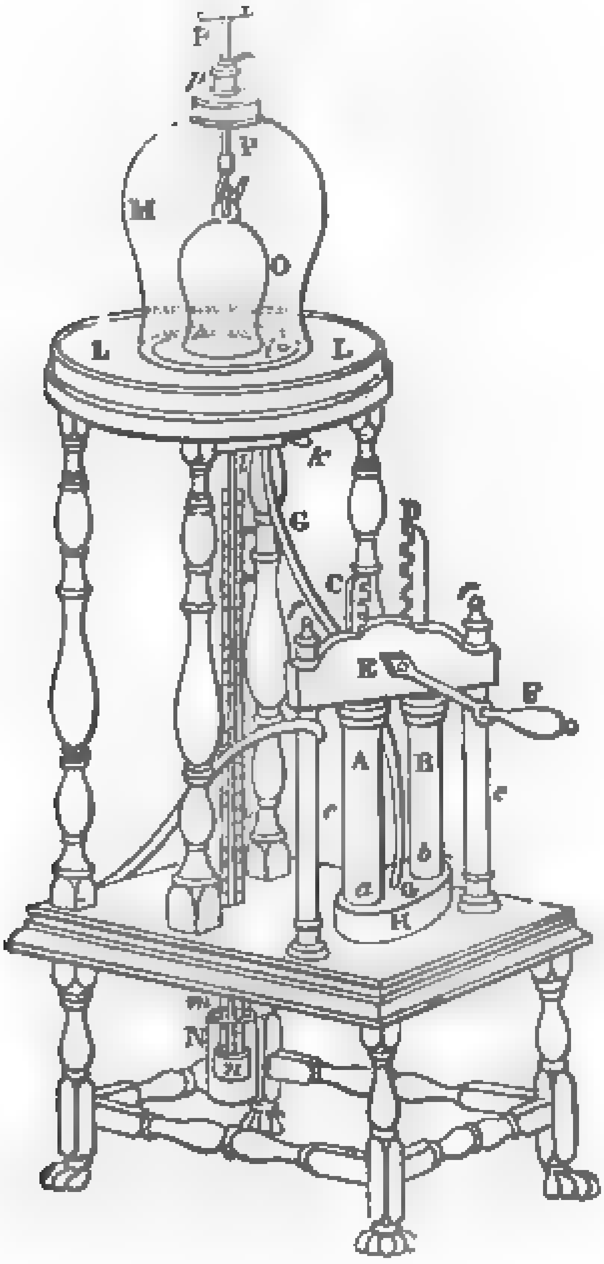
The *air-pump* being constructed the same way as the water-pump, whoever understands the one, will be at no loss to understand the other.[59]

Having put a wet leather on the plate *L L* of the air-

Note 58. Although the Editor has considered it adviseable to insert the paragraphs entitled *Fermentation, Thunder, Lightning, and Earthquakes,* he yet feels it his duty to say, that they are, in most particulars, inconsistent with sound philosophy. Our Author's Treatise on Electricity, adapted to the present state of science, is nearly ready for publication.

Note 59. We are indebted for the invention of the *air-pump* to a learned German, no less distinguished for his pneumatic knowledge, than general scientific attainments: and though the memory of Otto Guericke will be long remembered with gratitude and veneration, by every lover of science, we must still bear in mind, that it was our countryman Boyle who converted it to real use. In the hands of Otto Guericke it was an amusing toy, and a mere mechanical instrument: in those of Boyle it became a truly philosophical machine.

, place the glass receiver *M* upon the leather, so the hole *i* in the plate may be within the glass. , turning the handle *F* backward and forward, PLATE VI.



air will be pumped out of the receiver; which will be held down to the plate by the pressure he external air, or atmosphere. For, as the han-

the use of the *air-pump* we may, as will be presently shewn, ex- a vessel of its air, and thus compare the changes wrought upon s substances by being kept from air, with the same bodies when ed to the action of the atmosphere; so that we thus acquire a ledge of the effects of that fluid upon bodies in general.

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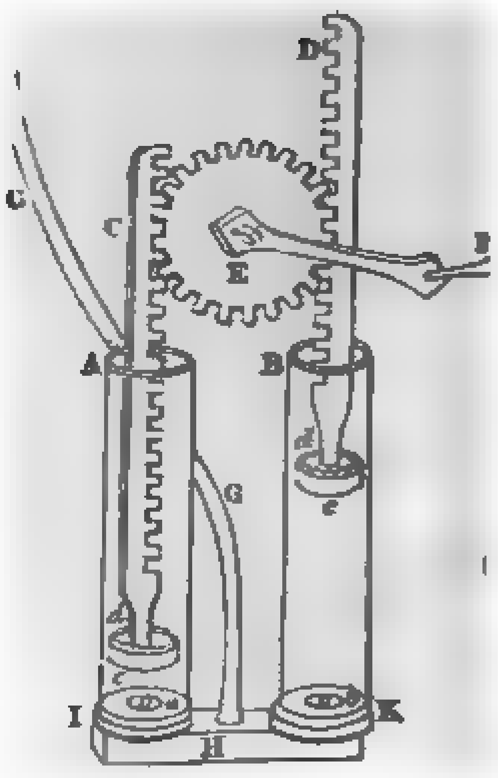
dle *F* is turned backwards, it raises the piston *d e* in the barrel *B K*, by means of the wheel *E* and rack *D d;* and, as the piston is leathered so tight as to fit the barrel exactly, no air can get beyond the piston-barrel; the air above *d* in the barrel, is lifted up towards *B*, and a vacuum is made in the barrel from *e* to *b;* upon which,



part of the air in the receiver *M* (of the prece diagram), by its spring, rushes through the *i*, in the brass plate *L L*, along the pipe *G C G* (w communicates with both barrels by the hollow t *I H K* (in the above diagram), and pushing up valve *b*, enters into the vacant place *b e* of the b *B K*. For, wherever the resistance or pressu taken off, the air will run to that place, if it can fi passage.—Then, if the handle *F* be turned forward, piston *d e* will be depressed in the barrel; and, a air which had got into the barrel cannot be pushed b through the valve *b*, it will ascend through a hol the piston, and escape though a valve at *d*; and be dered by that valve from returning into the barrel, v the piston is again raised. At the next raising o piston, a vacuum is again made in the same manne before, between *b* and *e;* upon which, more of the which was left in the receiver *M*, gets out thence b spring, and runs into the barrel *B K*, through the v *B*. The same thing is to be understood with regar the other barrel *A I;* and as the handle *F* is tu

backwards and forwards, it alternately raises and depresses the pistons in their barrels; always raising one whilst it depresses the other. And, as there is a vacuum made in each barrel when its piston is raised, every particle of air in the receiver *M* pushes out another, by its spring or elasticity, through the hole *i*, and pipe *G G* into the barrels; until at last the air in the receiver comes to be so much dilated, and its spring so far weakened, that it can no longer get through the valves; and then no more can be taken out. Hence, there is no such thing as making a perfect vacuum in the receiver; for the quantity of air taken out at any one stroke, will always be as the density thereof in the receiver: and therefore it is impossible to take it all out, because, supposing the receiver and barrels of equal capacity, there will be always as much left as was taken out at the last turn of the handle.

There is a cock *k* below the pump-plate, which being turned, lets air into the receiver again; and then the receiver becomes loose, and may be taken off the plate. The barrels are fixed to the frame *E e e* by two screw-nuts *f f*, which press down the top piece *E* upon the barrels: and the hollow trunk *H* (in page 208) is covered by a box, *G H* (in page 207.)

There is a glass tube *l m m m n* open at both ends, and about 34 inches long; the upper end communicating with the hole in the pump-plate, and the lower end immersed in quicksilver at *n* in the vessel *N*. To this tube is fitted a wooden ruler *m m*, called the *gage*, which is divided into inches and parts of an inch, from the bottom at *n* (where it is even with the surface of the quicksilver) and continued up to the top, a little below *l*, to 30 or 31 inches.

As the air is pumped out of the receiver *M*, it is likewise pumped out of the glass tube *l m n*, because that tube opens into the receiver through the pump-plate; and as the tube is gradually emptied of air, the quick

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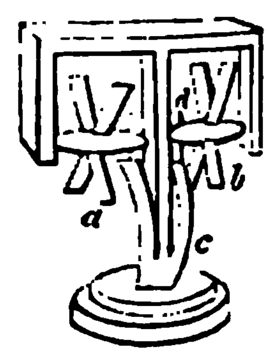
silver in the vessel *N* is forced up into the tube by the pressure of the atmosphere. And if the receiver could be perfectly exhausted of air, the quicksilver would stand as high in the tube as it does at that time in the barometer: for it is supported by the same power or weight of the atmosphere in both.

The quantity of air exhausted out of the receiver on each turn of the handle, is always proportionable to the ascent of the quicksilver, on that turn; and the quantity of air remaining in the receiver is proportionable to the defect of the height of the quicksilver in the gage, from what it is at that time in the barometer.

I shall now give an account of the experiments made with the air-pump in my Lectures; shewing the resistance, weight, and elasticity of the air.

1. *To shew the Resistance of the Air.*

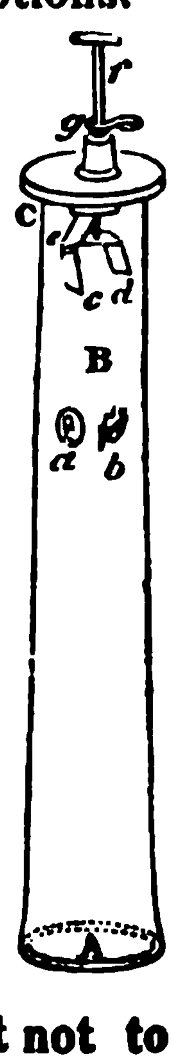


1. There is a little machine consisting of two mills, *a* and *b*, which are of equal weights, independent of each other, and turn equally free on their axes in the frame. Each mill has four thin arms or sails, fixed into the axis: those of the mill *a* have their planes at right angles to its axis, and those of *b* have their planes parallel to it, Therefore, as the mill *a* turns round in common air, it is but little resisted thereby, because its sails cut the air with their thin edges: but the mill *b* is much resisted, because the broad sides of its sails move against the air when it turns round. In each axle is a pin near the middle of the frame, which goes quite through the axle, and stands out a little on each side of it: upon these pins, the slider *d* may be made to bear, and so hinder the mills from going, when the strong spring *c* is set on bend against the opposite ends of the pins.

Having set this machine upon the pump-plate *L L* (page 207) draw up the slider *d* to the pins on one side

spring *c* at bend upon the opposite ends of hen push down the slider *d*, and the spring illy strong upon each mill, will set then both th equal forces and velocities; but the mill nuch longer than the mill *b*, because the air h less resistance against the edges of its against the sides of the sails of *b*.

the slider again, and set the spring upon the ore; then cover the machine with the receiver he pump plate, and having exhausted the air, push down the wire *P P* (through the athers in the neck *q*) upon the slider; which age it from the pins, and allow the mills to turn he impulse of the spring: and as there is no ceiver to make any sensible resistance against will both move a considerable time longer than the open air; and the moment that one stops, vill do so too.—This shews that air resists otion, and that equal bodies meet with different resistance, according as they present greater ace to the air in the planes of their motions.



off the receiver *M*, and the mills; put the guinea *a* and feather *b* upon ap *c*, turn up the flap, and shut it tch *d*. Then putting a wet leather p of the tall receiver *A B* (it being at top and bottom) cover it with the rom which the guinea and feather will then hang within the receiver. pump the air out of the receiver; raw up the wire *f* a little, which by iece on its lower end will open the and the flap falling down as at *c*, and feather will descend with equal n the receiver; and both will fall pump-plate at the same instant. n this experiment, the observers ought not to

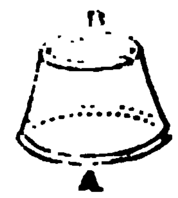
LECT. VI. look at the top, but at the bottom of the receiver; in order to see the guinea and feather fall upon the plate: otherwise, on account of the quickness of their motion, they escape the sight of the beholders.

2. *To shew the weight of the Air.*

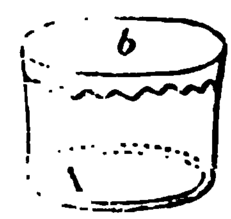
1. Having fitted a brass cap, with a valve tied over it, to the mouth of a thin bottle or *Florence* flask, whose contents are exactly known, screw the neck of this cap into the hole *i* of the pump-plate: then, having exhausted the air out of the flask, and taken it off from the pump let it be suspended at one end of a balance, and nicely counterpoised by weights in the scale at the other end: this done, raise up the valve with a pin, and the air will rush into the flask with an audible noise: during which time the flask will descend, and pull down that end of the beam. When the noise is over, put as many grains into the scale at the other end as will restore the equilibrium; and they will show exactly the weight of the quantity of air which has got into the flask, and filled it. If the flask holds an exact quart, it will be found, that 16 grains will restore the equipoise of the balance, when the quicksilver stands at 29½ inches in the barometer; which shows that when the air is at a mean rate of density, a quart of it weighs 16 grains: it weighs more when the quicksilver stands higher; and less when it stands lower.

2. Place the small receiver *O* (page 207) over the hole *i* in the pump-plate, and, upon exhausting the air, the receiver will be fixed down to the plate by the pressure of the air on its outside, which is left to act alone, without any air in the receiver to act against it: and this pressure will be equal to as many times 15 pounds, as there are square inches in that part of the plate which the receiver covers; which will hold down the receiver so fast, that it cannot be got off, until the air be let into it by turning the cock *k*; and then it becomes loose.

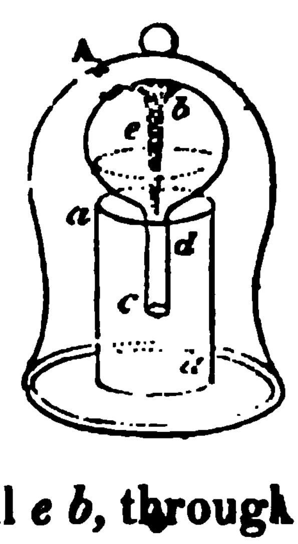
3. Set the little glass *A B* (which is open at both ends) over the hole *i* upon the pump-plate *L L*, and put your hand close upon the top of it at *B*: then upon exhausting the air out of the glass, you will find your hand pressed down with a great weight upon it: so that you can hardly release it, until the air be re-admitted into the glass by turning the cock *k*; which air, by acting as strongly upward against the hand as the external air acted in pressing it downward, will release the hand from its confinement.



4. Having tied a piece of wet bladder *b* over the open top of the glass *A* (which is also open at bottom) set it to dry; and then the bladder will be tight like a drum. Then place the open end *A* upon the pump-plate, over the hole *i*, and begin to exhaust the air out of the glass. As the air is exhausting, its spring in the glass will be weakened, and give way to the pressure of the outward air on the bladder, which, as it is pressed down, will put on a spherical concave figure, which will grow deeper and deeper, until the strength of the bladder be overcome by the weight of the air; and then it will break with a report as loud as that of a gun.—If a flat piece of glass be laid upon the open top of this receiver, and joined to it by a flat ring of wet leather between them; upon pumping the air out of the receiver, the pressure of the outward air upon the flat glass will break it all to pieces.



5. Immerse the neck *c d* of the hollow glass ball *e b* in water, contained in the phial *a a*; then set it upon the pump-plate, and cover it and the hole *i* with the close receiver *A*; and then begin to pump out the air. As the air goes out of the receiver by its spring, it will also by the same means go out of the hollow ball *e b*, through the neck *d c*, and rise up in bubbles to the surface of



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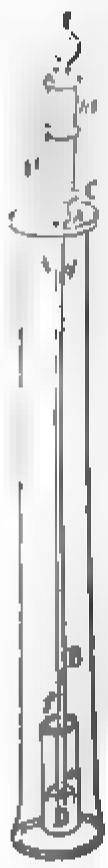
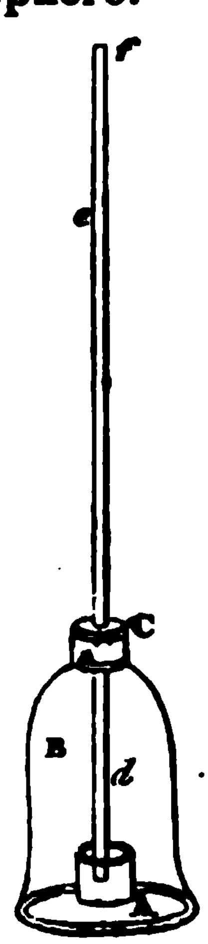
the water in the phial; from whence it will make its way, with the rest of the air in the receiver, through the air pipe *G G* and valves *a* and *b*, into the open air. When it has done bubbling in the phial, the ball is sufficiently exhausted; and then upon turning the cock *k*, the air will get into the receiver, and press so upon the surface of the water in the phial, as to force the water up into the ball in a jet, through the neck *c d*; and will fill the ball almost full of water. The reason why the ball is not quite filled, is, because all the air could not be taken out of it; and the small quantity that was left in, and had expanded itself so has to fill the whole ball, is now condensed into the same state as the outward air, and remains in a small bubble at the top of the ball; and so keeps the water from filling that part of the ball.

6. Pour some quicksilver into the jar *D*; and set it on the pump-plate near the hole *i*; then set on the tall open receiver *A B*, so as to be over the jar and hole; and cover the receiver with the brass plate *C*. Screw the open glass tube *f g* (which has a brass top on it at *h*) into the syringe *H*, and putting the tube through a hole in the middle of the plate, so as to immerse the lower end of the tube *e* in the quicksilver at *D*, screw the end *h* of the syringe into the plate. This done, draw up the piston in the syringe by the ring *I*, which will make a vacuum in the syringe, below the piston; and as the upper end of the tube opens into the syringe the air will be dilated in the tube because part of it, by its spring, gets up into the syringe; and the spring of the undilated air in the receiver acting upon the surface of the quicksilver in the jar, will force part of it up into the tube: for the quicksilver will follow the piston in the syringe, in the same way and for the same reason that water follows the piston of a common pump when it is raised in the pump-barrel; and this, according to



some, is done by suction. But to refute that erroneous notion, let the air be pumped out of the receiver *A B* and then all the quicksilver in the tube will fall down by its own weight into the jar; and cannot be again raised one hair's breadth in the tube by working the syringe; which shews that suction had no hand in raising the quicksilver; and, to prove that it is done by pressure let the air into the receiver by the cock *k* (page 207), and its action upon the surface of the quicksilver in the jar will raise it up into the tube, although the piston of the syringe continues motionless.—If the tube be about 32 or 33 inches high, the quicksilver will rise in it very near as high as it stands at that time in the barometer. And if the syringe has a small hole, as *m*, near the top of it, and the piston be drawn up above that hole, the air will rush through the hole into the syringe and tube, and the quicksilver will immediately fall down into the jar. If this part of the apparatus be air-tight, the quicksilver may be pumped up into the tube to the same height that it stands in the barometer; but it will go no higher, because then the weight of the column in the tube is the same as the weight of a column of air of the same thickness with the quicksilver, and reaching from the earth to the top of the atmosphere.

7. Having placed the jar *A*, with some quicksilver in it, on the pump-plate, as in the last experiment, cover it with the receiver *B*; then push the open end of the glass tube *d e* through the collar of leathers in the brass neck *C* (which it fits so as to be air-tight) almost down to the quicksilver in the jar. Then exhaust the air out of the receiver, and it will also come out of the tube because the tube is close at top. When the guage *m m* shews that the receiver is well exhausted, push down the tube, so as to immerse its lower end into the quicksilver in the jar.



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Now, although the tube be exhausted of air, none of the quicksilver will rise into it, because there is no air left in the receiver to press upon its surface in the jar. But let the air into the receiver by the cock *k*, and the quicksilver will immediately rise in the tube; and stand as high in it, as it was pumped up in the last experiment.

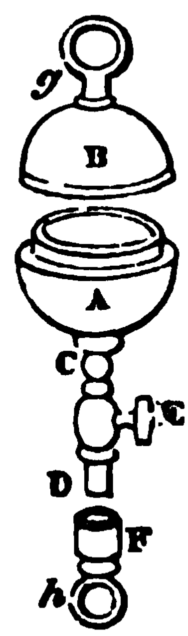
Both these experiments shew, that the quicksilver is supported in the barometer by the pressure of the air on its surface in the box, in which the open end of the tube is placed. And that the more dense and heavy the air is, the higher does the quicksilver rise; and, on the contrary, the thinner and lighter the air is, the more will the quicksilver fall. For if the handle *F* be turned ever so little, it takes some air out of the receiver, by raising one or other of the pistons in its barrel; and consequently that which remains in the receiver is so much the rarer, and has so much the less spring and weight; and thereupon, the quicksilver falls a little in the tube: but upon turning the cock, and re-admitting the air into the receiver, it becomes as weighty as before, and the quicksilver rises again to the same height.—Thus we see the reason why the quicksilver in the barometer falls before rain or snow, and rises before fair weather; for, in the former case, the air is too thin and light to bear up the vapours, and in the latter, too dense and heavy to let them fall.

N. B. In all mercurial experiments with the air-pump, a short pipe must be screwed into the hole *i*, so as to rise about an inch above the plate, to prevent the quicksilver from getting into the air-pump and barrels, in case any of it should be accidentally spilt over the jar: for if it once gets into the pipes or barrels, it spoils them, by loosening the solder, and corroding the brass.

8. Take the tube out of the receiver, and put one end of a bit of dry hazel branch, about an inch long, tight into the hole, and the other end tight into a hole quite through the bottom of a small wooden cup: then

pour some quicksilver into the cup, and exhaust the receiver of air, and the pressure of the outward air, on the surface of the quicksilver, will force it through the pores of the hazel, from whence it will descend in a beautiful shower into a glass cup placed under the receiver to catch it.

9. Put a wire through the collar of leathers in the top of the receiver, and fix a bit of dry wood on the end of the wire within the receiver; then exhaust the air, and push the wire down, so as to immerse the wood into a jar of quicksilver on the pump-plate; this done, let in the air, and, upon taking the wood out of the jar, and splitting it, its pores will be found full of quicksilver, which the force of the air, upon being let into the receiver, drove into the wood.

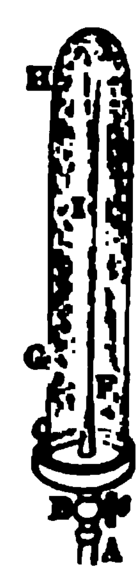


10. Join the two brass hemispherical cups *A* and *B* together, with a wet leather between them, having a hole in the middle of it; then screw the end *D* of the pipe *C D* in the plate of the pump at *i*, and turn the cock *E*, so as the pipe may be open all the way into the cavity of the hemispheres: then exhaust the air out of them, and turn the cock a quarter round, which will shut the pipe *C D*, and keep out the air. This done, unscrew the pipe at *D* from the pump; and screw the piece *Fh* upon it at *D*; and let two strong men try to pull the hemispheres asunder by the rings *g* and *h*, which they will find it hard to do: for if the diameter of the hemispheres be four inches, they will be pressed together by the external air with a force equal to 190 pounds. And to shew that it is the pressure of the air that keeps them together, hang them by either of the rings upon the hook *P* of the wire in the receiver *M* (page 207,) and upon exhausting the air out of the receiver, they will fall asunder of themselves.

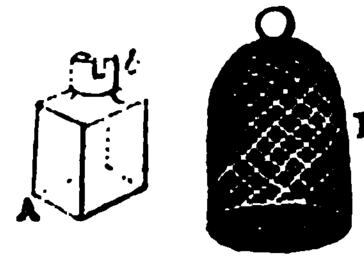
11. Place a small receiver *O* (page 207) near the hole

LECT. VI. *i* on the pump-plate, and cover both it and the hole with the receiver *M;* and turn the wire so by the top *P,* that its hook may take hold of the little receiver by a ring at its top, allowing that receiver to stand with its own weight on the plate. Then, upon working the pump, the air will come out of both receivers; but the large one *M* will be forcibly held down to the pump by the pressure of the external air; whilst the small one *O,* having no air to press upon it, will continue loose, and may be drawn up and let down at pleasure, by the wire *P P.* But, upon letting it quite down to the plate, and admitting the air into the receiver *M,* by the cock *k,* the air will press so strongly upon the small receiver *O,* as to fix it down to the plate; and, at the same time, by counterbalancing the outward pressure on the large receiver *M,* it will become loose. This experiment evidently shews, that the receivers are held down by pressure, and not by suction, for the internal receiver continued loose whilst the operator was pumping, and the external one was held down; but the former became fast immediately by letting in the air upon it.

12. Screw the end *A* of the brass pipe *A B F* into the hole of the pump-plate, and turn the cock *e* until the pipe be open; then put a wet leather upon the plate *c d,* which is fixed on the pipe, and cover it with the tall receiver *G H,* which is close at top: then exhaust the air out of the receiver, and turn the cock *e* to keep it out; which done, unscrew the pipe from the pump, and set its end *A* into a bason of water, and turn the cock *e* to open the pipe; on which, as there is no air in the receiver, the pressure of the atmosphere on the water in the bason will drive the water forcibly through the pipe, and make it play up in a jet to the top of the receiver.



13. Set the square phial *A* upon the pump-plate, and having covered it with the wire-cage *B*, put a close receiver over it, and exhaust the air out of the receiver; in doing of which, the air will also make its way out of the phial through a small hole in its neck under the valve *b*. When the air is exhausted, turn the cock below the plate, to re-admit the air into the receiver; and, as it cannot get into the phial again, because of the valve, the phial will be broken into some thousands of pieces by the pressure of the air upon it. Had the phial been of a round form, it would have sustained this pressure like an arch, without breaking; but as its sides are flat, it cannot.



To shew the Elasticity or Spring of the Air.

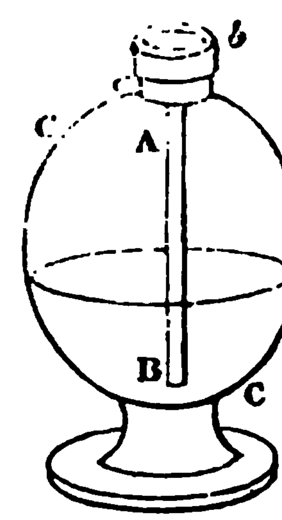
14. Tie up a very small quantity of air in a bladder, and put it under a receiver; then exhaust the air out of the receiver; and the small quantity which is confined in the bladder (having nothing to act against it) will expand itself so by the force of its spring, as to fill the bladder as full as it could be blown of common air But upon letting the air into the receiver again, it will overpower the air in the bladder, and press its sides almost close together.

15. If the bladder, so tied up, be put into a wooden box, and have 20 or 30 pounds weight of lead put upon it in the box, and the box be covered with a close receiver; upon exhausting the air out of the receiver, that air which is confined in the bladder will expand itself so as to raise up all the lead by the force of its spring.

16. Take the glass ball, mentioned in the fifth experiment (page 213,) which was left full of water all but a small bubble of air at top, and having set it with its

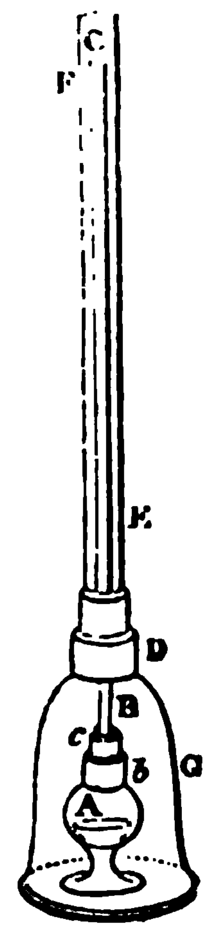
LECT. VI. neck downward into the empty phial *a a*, and covered it with a close receiver, exhaust the air out of the receiver, and the small bubble of air in the top of the ball will expand itself, so as to force all the water out of the ball into the phial.

17. Screw the pipe *A B* into the pump-plate, place the tall receiver *G H* upon the plate *c d*, as in the twelfth experiment, and exhaust the air out of the receiver; then, turn the cock *e* to keep out the air, unscrew the pipe from the pump, and screw it into the mouth of the copper vessel *C C*, the vessel having first been about half filled with water. Then open the cock *e* (page 218) and the spring of the air which is confined in the copper vessel will force the water up through the pipe *A B* in a jet into the exhausted receiver, as strongly as it did by its pressure on the surface of the water in a bason, in the twelfth experiment.

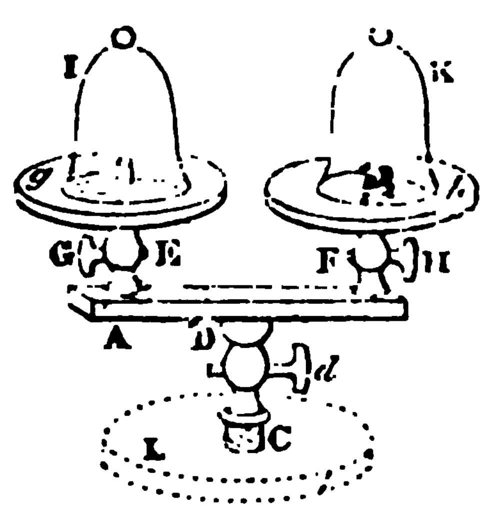


18. If a fowl, a cat, rat, mouse, or bird, be put under a receiver, and the air be exhausted, the animal will be at first oppressed as with a great weight, then grow convulsed, and at last expire in all the agonies of a most bitter and cruel death. But as this experiment is too shocking to any spectator who has the least degree of humanity, we substitute a machine called the *lungs-glass* in place of the animal.

19. If a butterfly be suspended in a receiver, by a fine thread tied to one of its horns, it will fly about in the receiver, as long as the receiver continues full of air; but if the air be exhausted, though the animal will not die, and will continue to flutter its wings, it cannot remove itself from the place where it hangs in the middle of the receiver, until the air be let in again, and then the animal will fly about as before.



20. Pour some quicksilver into the small bottle *A*, and screw the brass collar *c* of the tube *B C* into the brass neck *b* of the bottle, and the lower end of the tube will be immersed into the quicksilver, so that the air above the quicksilver in the bottle will be confined there, because it cannot get out about the joinings, nor can it be drawn out through the quicksilver into the tube. This tube is also open at top, and is to be covered with the receiver *G* and large tube *E F*, which tube is fixed by brass collars to the receiver, and is close at the top. This preparation being made, exhaust the air both out of the receiver and its tube; and the air will, by the same means, be exhausted out of the inner tube *B C*, through its open top at *C;* and as the receiver and tubes are exhausting, the air that is confined in the glass bottle *A* will press so by its spring upon the surface of the quicksilver, as to force it up in the inner tube as high as it was raised in the ninth experiment by the pressure of the atmosphere: which demonstrates that the spring of the air is equivalent to its weight.



21. Screw the end *C* of the pipe *C D* into the hole of the pump-plate, and turn all the three cocks *d*, *G*, and *H*, so as to open the communications between all the three pipes *E*, *F*, *D C*, and the hollow trunk *A B*. Then, cover the plates *g* and *h* with wet leathers, which have holes in their middle where the pipes open into the plates; and place the close receiver *I* upon the plate *g:* this done, shut the pipe *F* by turning the cock *H*, and exhaust the air out of the receiver

LECT. VI. *I*. Then, turn the cock *d* to shut out the air, unscrew the machine from the pump, and having screwed it to the wooden foot *L*, put the receiver *K* upon the plate *h*; this receiver will continue loose on the plate as long as it keeps full of air; which it will do until the cock *H* be turned to open the communication between the pipes *F* and *E*, through the trunk *A B*; and then the air in the receiver *K*, having nothing to act against its spring, will run from *K* into *I*, until it be so divided between these receivers, as to be of equal density in both; and then they will be held down with equal forces to their plates by the pressure of the atmosphere; though each receiver will then be kept down but with one half of the pressure upon it, that the receiver *I* had, when it was exhausted of air; because it has now one half of the common air in it which filled the receiver *K* when it was set upon the plate; and therefore, a force equal to half the force of the spring of common air, will act within the receivers against the whole pressure of the common air upon their outsides. This is called transferring the air out of one vessel into another.

22. Put a cork into the square phial *A* (page 219,) and fix it in with wax or cement; put the phial upon the pump-plate with the wire cage *B* over it, and cover the cage with a close receiver. Then, exhaust the air out of the receiver, and the air that was corked up in the phial will break the phial outwards by the force of its spring, because there is no air left on the outside of the phial to act against the air within it.

22. Put a shrivelled apple under a close receiver, and exhaust the air; then the spring of the air within the apple will plump it out, so as to cause all the wrinkles to disappear; but upon letting the air into the receiver again, to press upon the apple, it will instantly return to its former decayed and shrivelled state.

23. Take a fresh egg, and cut off a little of the shel

and film from its smallest end, then put the egg under a receiver, and pump out the air; upon which all the contents in the egg will be forced out into the receiver, by the expansion of a small bubble of air contained in the great end, between the shell and film.

24. Put some warm beer in a glass, and having set it on the pump, cover it with a close receiver, and then exhaust the air. Whilst this is doing, and thereby the pressure more and more taken off from the beer in the glass, the air therein will expand itself, and rise up in innumerable bubbles to the surface of the beer; and from thence it will be taken away with the other air in the receiver. When the receiver is nearly exhausted, the air in the beer, which could not disentangle itself quick enough to get off with the rest, will now expand itself so as to cause the beer to have all the appearance of boiling; and the greatest part of it will go over the glass.

25. Put some warm water in a glass, and put a bit of dry wainscot or other wood into the water. Then, cover the glass with a close receiver, and exhaust the air; upon which, the air in the wood, having liberty to expand itself, will come out plentifully, and make all the water to bubble about the wood, especially about the ends, because the pores lie lengthwise. A cubic inch of dry wainscot has so much air in it, that it will continue bubling for near half an hour together.

Miscellaneous Experiments.

26. Screw the syringe *H* (page 214) to a piece of lead that weighs one pound at least; and, holding the lead in one hand, pull up the piston in the syringe with the other; then, quitting hold of the lead, the air will push it upward, and drive back the syringe upon the piston. The reason of this is, that the drawing up of the piston makes a vacuum in the syringe, and the air, which presses every way equally, having nothing to

LECT. VI. resist its pressure upward, the lead is thereby pressed upward, contrary to its natural tendency by gravity. If the syringe, so loaded, be hung in a receiver, and the air be exhausted, the syringe and lead will descend upon the piston-rod by their natural gravity; and, upon admitting the air into the receiver, they will be driven upward again, until the piston be at the very bottom of the syringe.

27. Let a large piece of cork be suspended by a thread at one end of a balance, and counterpoised by a leaden weight, suspended in the same manner at the other. Let this balance be hung to the inside of the top of a large receiver; which being set on the pump, and the air exhausted, the cork will preponderate, and shew itself to be heavier than the lead; but upon letting in the air again, the equilibrium will be restored. The reason of this is, that since the air is a fluid, and all bodies lose as much of their absolute weight in it, as is equal to the weight of the bulk of the fluid, the cork being the larger body, loses more of its real weight than the lead does; and therefore must in fact be heavier, to balance it under the disadvantage of losing some of its weight; which disadvantage being taken off by removing the air, the bodies then gravitate according to their real quantities of matter, and the cork which, balanced the lead in air, shews itself to be heavier when *in vacuo*.[60]

28. Set a lighted candle upon the pump, and cover it with a tall receiver. If the receiver holds a gallon, the candle will burn a minute; and then, after having gradually decayed from the first instant, it will go out: which shews, that a constant supply of fresh air is ne-

Note 60. This experiment may be adduced as an answer to the common query "Which is heaviest, a pound of lead, or a pound of feathers?" and a reference to the fact of the air's buoyancy will shew that the larger body, or the one whose specific gravity is least, must of necessity have the greatest portion of its weight subtracted.

cessary to feed flame; and so it also is for animal life. For a bird kept under a close receiver will soon die, although no air be pumped out; and it is found that, in the diving-bell, a gallon of air is sufficient only for one minute for a man to breathe in.[a]

The moment when the candle goes out, the smoke will be seen to ascend to the top of the receiver, and there it will form a sort of cloud: but upon exhausting the air, the smoke will fall down to the bottom of the receiver, and leave it as clear at the top as it was before it was set upon the pump. This shews, that smoke does not ascend on account of its being positively light, but because it is lighter than air; and its falling to the bottom when the air was taken away, shews, that it is not destitute of weight. So most sorts of wood ascend or swim in water; and yet there are none who doubt of the wood's having gravity or weight.

29. Set a receiver, which is open at top, upon the air-pump, and cover it with a brass plate, and wet leather; and having exhausted it of air, let the air in again at top through an iron pipe, making it pass through a charcoal flame; at the end of the pipe; and when the receiver is full of that air, lift up the cover, and let down a mouse or bird into the receiver, and the burned air will immediately kill it. If a candle be let down into the air, it will go out directly; but, by letting it down gently, it will purify the air so far as it goes; and so, by letting it down more and more, all the air in the receiver will be purified.

30. Set a bell upon a cushion on the pump-plate, and

Note 61. It has already been stated that oxygen gass is essential to combustion—a fact fully proved by the above experiment; and it might, at first view, be supposed that an excess of this important ingredient of our atmosphere, might be an additional comfort to those who inhale it. The contrary, however, is the case; as Infinite Wisdom has so apportioned the compound, that the slightest addition to the vivifying principle would lessen, if not entirely destroy the advantages arising from artificial illumination by rendering combustion too rapid.

LECT. VI. cover it with a receiver; then shake the pump to make the clapper strike against the bell, and the sound will be very well heard: but, exhaust the receiver of air, and then, if the clapper be made to strike ever so hard against the bell, it will make no sound at all; which shews, that air is absolutely necessary for the propagation of sound.[62]

31. Let a candle be placed on one side of a receiver and viewed through the receiver at some distance: then, as soon as the air begins to be exhausted, the receiver will be filled with vapours which rise from the wet leather, by the spring of the air in it; and the light of the candle being refracted through that medium of vapours, will have the appearance of circles of various colours, of a faint resemblance to those in the rainbow.

The air-pump was invented by *Otto Guericke* of *Magdeburg*, but was much improved by *Mr. Boyle*, to whom we are indebted for our greatest part of the knowledge of the wonderful properties of the air, demonstrated in the above experiments.

The elastic air which is contained in many bodies, and is kept in them by the weight of the atmosphere, may be got out of them either by boiling, or by the air-pump, as shewn in the 25th experiment; but the fixed air which is by much the greater quantity, cannot be got out but by distillation, fermentation, or putrefaction.

If fixed air did not come out of bodies with difficulty, and spend some time in extricating itself from them, it would tear them to pieces. Trees would be rent by the change of air from a fixed to an elastic state, and animals would be burst in pieces by the explosion of air in their food.

Dr. Hales found, by experiment, that the air in apples is so much condensed, that if it were let out into the common air, it would fill a space of 48 times as great as

Note 62. The above assertion is a vulgar error, as sound may be transmitted by most bodies. Air, indeed, is the ordinary vehicle by which it is propagated, but it is not the only medium.

the bulk of the apples themselves; so that its pressure was equal to 11776 pounds, and in a cubic inch of oak, to 19860 pounds against their sides. So that if the air was let loose at once in these substances, they would tear every thing to pieces about them with a force superior to that of gunpowder. Hence, in eating apples, it is well that they part with the air by degrees, as they are chewed, and ferment in the stomach, otherwise an apple would be immediate death to him who eats it.

The mixing of some substances with others will release the air from them, all of a sudden, which may be attended with very great danger. Of this we have a remarkable instance in an experiment made by *Dr. Slare;* who having put half a dram of oil of carraway seed into one glass, and a dram of compound spirit of nitre in another, covered them both on theair-pump, with a receiver, six inches wide, and eight inches deep, and then exhausted the air, and continued pumping until all that could possibly be got both out of the receiver, and out of the two fluids was extricated, then, by a particular contrivance from the top of the receiver, he mixed the fluids together; upon which they produced such a prodigious quantity of air, as instantly blew up the receiver, although it was pressed down by the atmosphere with upwards of 400 pounds weight.

N. B. In the 28th experiment, the cork must be covered all over with a piece of thin wet bladder glued to it, and not used until it be thoroughly dry.

LECT. VII.

LECTURE VII.

OF OPTICS.

LIGHT consists of an inconceivably great number of particles flowing from a luminous body in all manner of directions; and these particles are so small, as to surpass all human comprehension.

That the number of particles of light is inconceivably great, appears from the light of a candle; which, if there be no obstacle in the way to obstruct the passage of its rays, will fill all the space within two miles of the candle every way, with luminous particles, before it has lost the least sensible part of its substance.

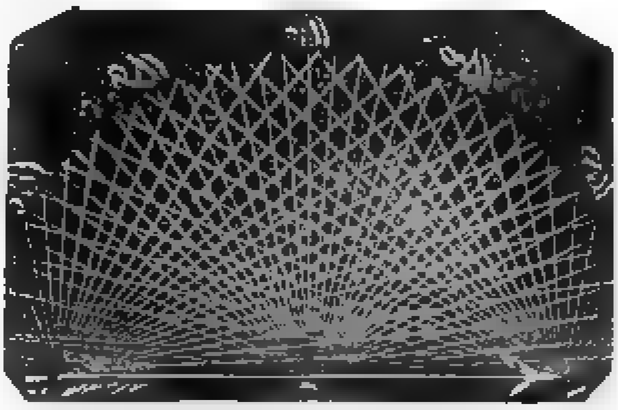
A ray of light is a continued stream of these particles, flowing from every visible body in a straight line: and that the particles themselves are incomprehensibly small, is manifest from the following experiment. Make a small pin-hole in piece of black paper, and hold the paper upright on a table facing a row of candles standing by one another; then place a sheet of paste-board at a little distance behind the paper, and some of the rays which flow from all the candles through the hole in the paper, will form as many specks of light on the paste-board, as there are candles on the table before the plate: each speck being as distinct and clear, as if there was only one speck from one single candle: which shews, that the particles of light are exceedingly small, otherwise they could not pass through the hole from so many different candles without confusion.—*Dr. Niewentyt* has computed, that there flows more than 6,000,000,000,000 times as many particles of light from a candle in one second of time, as there are grains of sand in the whole earth, supposing each cubic inch of it to contain 1,000,000.

The amazing smallness of the particles of light.

These particles, by falling directly upon our eyes,

excite in our minds the idea of light. And when they fall upon bodies, and are thereby reflected to our eyes, they excite in us the ideas of these bodies. And as every point of a visible body reflects the rays of light in all manner of directions, every point will be visible in every part to which the light is reflected from it. Thus the object *A C B* is visible to an eye in any part where the rays *A a*, *A b*, *A c*, *A d*, *A e*, *B a*, *B b*, *B c*, *B d*, *B e*, and *C a*, *C b*. *C c*, *C d*, *C e*, come. Here we have shewn the rays as if they were only reflected from the ends *A* and *B*, and from the middle point C of the object; every other point being supposed to reflect rays in the same manner. So that wherever a spectator is placed with regard to the body, every point of that part of the surface which is towards him will be visible, when no intervening object stops the passage of the light.

LECT. VII.



Reflected light.

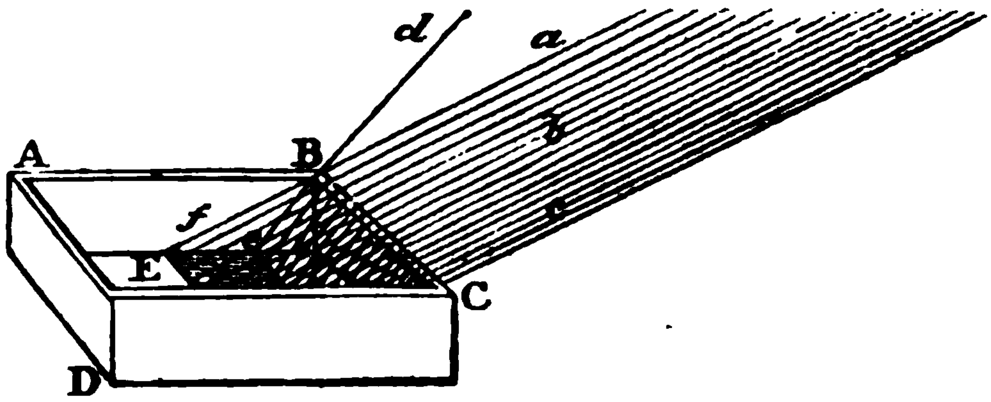
Since no object can be seen through the bore of a bended pipe, it is evident that the rays of light move in straight lines, whilst there is nothing to refract or turn them out of their rectilineal course.

Whilst the rays of light continue in any medium* of a uniform density, they are straight; but when they pass obliquely out of one medium into another, which is either more dense or more rare, they are refracted towards the denser medium: and this refraction is more or less, as the rays fall more or less obliquely on the refracting surface which divides the mediums.

Note 63. Any thing through which the rays of light can pass, is called a medium; as air, water, glass, diamond, or even a vacuum. —*Note by the Author*.

LECT. VII.

To prove this by experiment; set the empty vessel



A B C D into any place where the sun shines obliquely and observe the part where the shadow of the edge *BC* falls on the bottom of the vessel at *E;* then fill the vessel with water, and the shadow will reach no farther than *e;* which shews, that the ray *a B E,* which came straight in the open air, just over the edge of the vessel at *B* to its bottom at *E,* is refracted by falling obliquely on the surface of the water at *B;* and instead of going on in the rectilineal direction *a B E,* it is bent downward in the water from *B* to *e;* the whole bend being at the surface of the water: and so of all the other rays *a b c.*

Refracted light.

If a stick be laid over the vessel, and the sun's rays be reflected from a glass perpendicularly into the vessel, the shadow of the stick will fall upon the same part of the bottom, whether the vessel be empty or full; which shews that the rays of light are not refracted when they fall perpendicularly on the surface of any medium.

The rays of light are as much refracted by passing out of water into air, as by passing out of air into water. Thus, if a ray of light flows from the point *e,* under water, in the direction *e B;* when it comes to the surface of the water at *B,* it will not go on thence in the rectilineal course *B d,* but will be refracted into the line *B a.* Therefore,

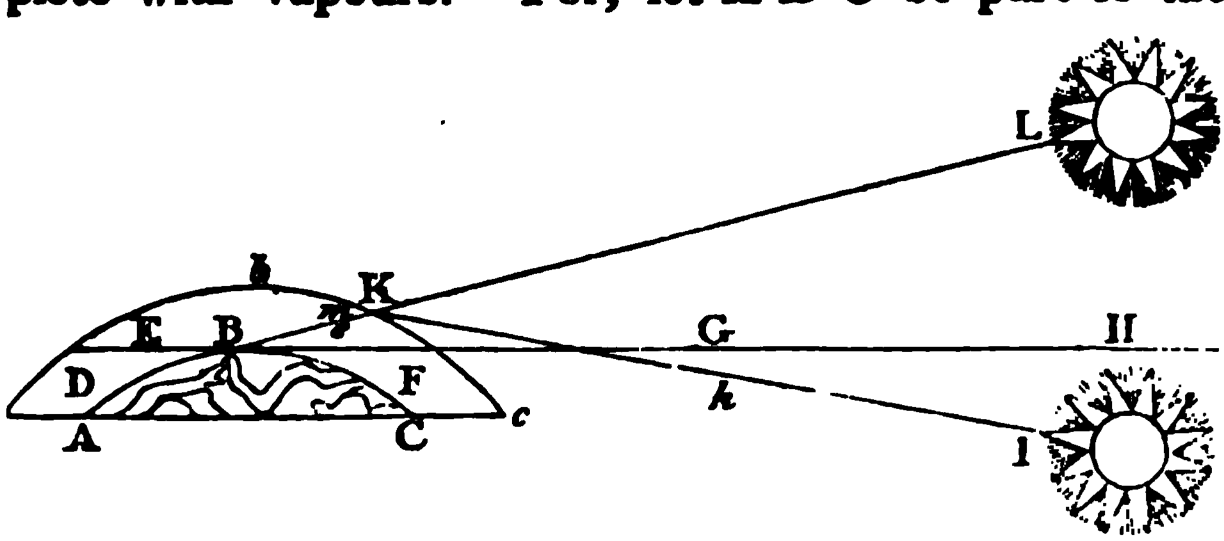
To an eye at *e* looking through a plane glass in the bottom of the empty vessel, the point *a* cannot be seen, because the side *B c* of the vessel interposes; and the point *d* will just be seen over the edge of the vessel at

LECT. VII.

. But if the vessel be filled with water, the point *a* ll be seen from *e*; and will appear as at *d*, elevated in e direction of the ray *e B*.[64]

The days are made longer by the refraction of the sun's rays

The time of sun-rising or setting, supposing its rays ffered no refraction, is easily found by calculation. ıt observation proves that the sun rises sooner, and ts later every day than the calculated time; the ason of which is plain from what was said immediately ove. For, though the sun's rays do not come part of e way to us through water, yet they do through the : or atmosphere, which being a grosser medium than e free space between the sun and the top of the atosphere, the rays by entering obliquely into the atosphere, are there refracted, and thence bent down to e earth. And although there are many places of the rth to which the sun is vertical at noon, and conseently his rays can suffer no refraction at that time, cause they come perpendicularly through the atmohere: yet there is no place to which the sun's ys do not fall obliquely on the top of the atmohere, at his rising and setting; and consequently, no ear day in which the sun will not be visible before he ies in the horizon, and after he sets in it; and the nger, or shorter, as the atmosphere is more or less plete with vapours. For, let *A B C* be part of the



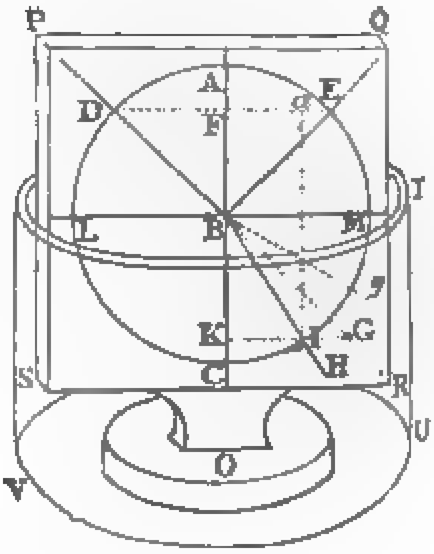
Note 64. Hence a piece of money lying at *e*, in the bottom of an ıpty vessel, cannot be seen by an eye at *a*, because the edge of the ssel intervenes; but let the vessel be filled with water, and the y *e a* being then refracted at *B*, will strike the eye at *a*, and so renr the money visible, which will appear as if it were raised up to *f* the line *a B f*.

LECT. VII.

earth's surface, *D E F* the atmosphere that covers it, and *E B G H* the sensible horizon of an observer at *B*. As every point of the sun's surface sends out rays of light in all manner of directions, some of his rays will constantly fall upon, and enlighten, some half of the atmosphere; and therefore, when the sun is at *I*, below the horizon *H*, those rays which go on in the free space *I k K* preserve a rectilineal course until they fall upon the top of the atmosphere; and those which fall so about *K*, are refracted at their entrance into the atmosphere and bent down in the line *K m B*, to the observer's place at *B*: and therefore to him, the sun will appear at *L*, in the direction of the ray *B m K*, above the horizon *B G H*, when he is really below it at *I*.

Angle of incidence. *Angle of refraction.*

The angle contained between a ray of light, and a perpendicular to the refracting surface, is called *the angle of incidence;* and the angle contained between the same perpendicular, and the same ray after refraction, is called *the angle of refraction.* Thus, let *L B M* be the refracting surface of a medium (suppose water), and *A B C* a perpendicular to that surface; let *D B* be a ray of light, going out of air into water at *B*, and therein refracted in the line *B H*; the angle *A B D* is the angle of incidence, of which *D F* is the sine; and the angle *K B H* is the angle of refraction, whose sine is *K I*.



When the refracting medium is water, the sine of the angle of incidence is to the sine of the angle of refraction, as 4 to 3: which is confirmed by the following experiment, taken from Doctor SMITH'S Optics.

Describe the circle *D A E C* on a plane square board, and cross it at right angles with the straight lines *A B C*,

L B M; then, from the intersection *A,* with any ning of the compasses, set off the equal arcs *A D* *A E,* and draw the right line *D F E:* then, taking , which is three quarters of the length *F E,* from the nt *a,* draw *a I* parallel to *A B K,* and join *K I,* pa-lel to *B M:* so *K I* will be equal to three quarters *F E* or of *D F.* This done, fix the board upright on the leaden pedestal *O,* and stick three pins per-ndicularly into the board, at the points *D, B,* and *I:* en set the board upright into the vessel *T U V,* and up the vessel with water to the line *L B M.* When e water has settled, look along the line *D B,* so as u may see the head of the pin *B* over the head of the n *D;* and the pin *I* will appear in the same right line oduced to *G,* for its head will be seen just over the ad of the pin at *B:* which shews that the ray *I B,* ming from the pin at *I,* is so refracted at *B,* as to oceed from thence in the line *B D* to the eye of the server; the same as it would do from any point *G* in right line *D B G,* if there were no water in the ssel: and also shews that *K I,* the sine of refraction water, is to *D F,* the sine of incidence in air, as 3 4.[65]

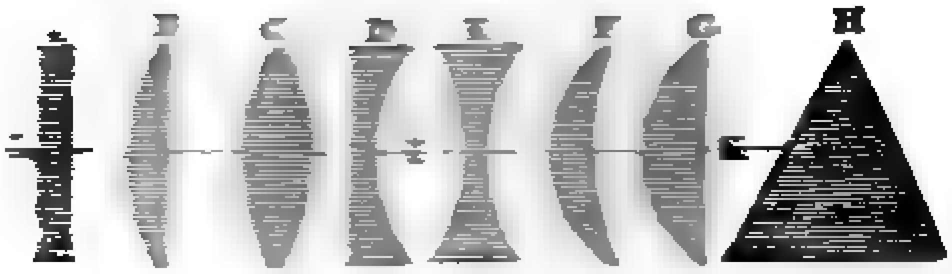
Hence, if *D B H* were a crooked stick put obliquely o the water, it would appear a straight one, as *D B G.* erefore, as the line *B H* appears at *B G,* so the line G will appear at *B g;* and consequently, a straight ck *D B G* put obliquely into water, will seem bent at surface of the water in *B,* and crooked, as *D B g.*

When a ray of light passes out of air into glass, the e of incidence is to the sine of refraction, as 3 to 2; d when out of air into a diamond, as 5 to 2.

Glass may be ground into eight different shapes at ast, for optical purposes, viz.

Note 65. This is strictly true of the red rays only, for the other oured rays are differently refracted; but the difference is so small, at it need not be considered in this place.—*Note by the Author.*

Lect. VI.



1. A *plane glass*, which is flat on both sides, and of equal thickness in all its parts, as A.

Lenses. 2. A *plano-convex*, which is flat on one side, and convex on the other, as B.

3. A *double convex*, which is convex on both sides, as C.

4. A *plano-concave*, which is flat on one side, and concave on the other, as D.

5. A *double concave*, which is concave on both sides, as E.

6. A *meniscus*, which is concave on one side, and convex on the other, as F.

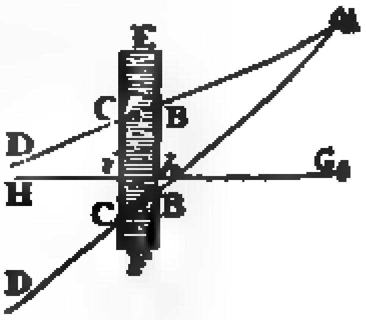
7. A *flat plano-convex*, whose convex side is ground into several little flat surfaces, as G.

8. A *prism*, which has three flat sides, and when viewed endwise, appears like an equilateral triangle, as H.

Glasses ground into any of the shapes B, C, D, E, F, are generally called *lenses*.

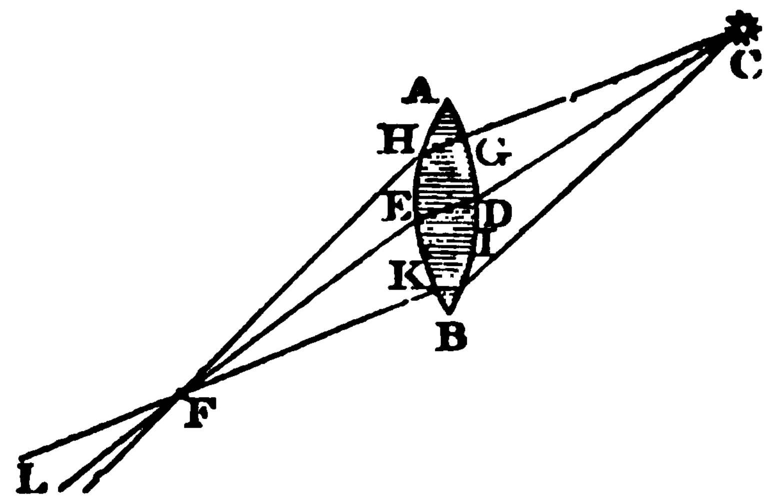
A right line L I K, going perpendicularly through the middle of a lens, is called *the axis of the lens*.

A ray of light G h, falling perpendicularly on a plane glass, E F, will pass through the glass in the same direction h i, and go out of it into the air in the same right course i H.



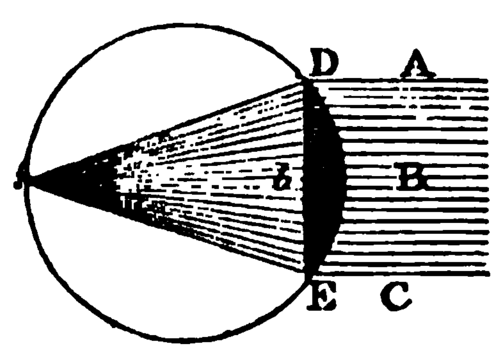
A ray of light A B, falling obliquely on a plane glass, will go out of the glass in the same direction, but not in the same right line; for in touching the glass, it will be refracted in the line B C,

nd, in leaving the glass, it will be refracted in the line *C D*. LECT. VII.

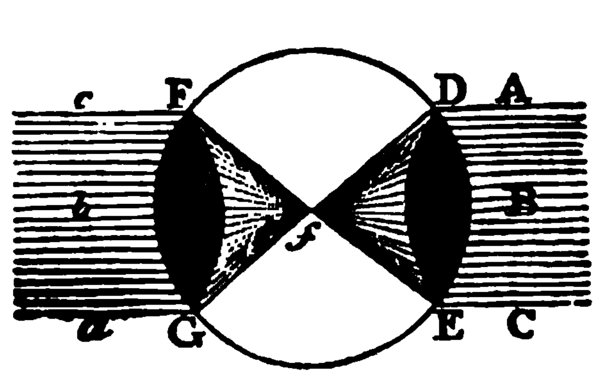


A ray of light *C D*, falling obliquely on the middle of a convex glass, will go forward in the same direction *D E*, as if it had fallen with the same degree of obliquity on a plane glass; and will go out of the glass in the same direction with which it entered: for it will be equally refracted at the points *D* and *E*, as if it had passed through a plane surface. But the rays *C G* and *C I* will be so refracted, as to meet again at the point *F*. Therefore, all the rays which flow from the point *C*, so as to go through the glass, will meet again at *F*; and if they go farther onward, as to *L*, they cross at *F*, and go forward on the opposite sides of the middle ray *C D E F*, to what they were in approaching it in the directions *H F* and *K F*.

The properties of different lenses.



When the parallel rays, as *A B C*, fall directly upon a plano-convex glass *D E*, and pass through it, they will be so refracted, as to unite in a point *f* behind it; and this point is called the *principal focus*; the distance of which, from the middle of the glass, is called the *focal distance*; which is equal to twice the radius of the sphere of the glass's convexity. And,



When parallel rays, as *A B C*, fall directly upon a glass *D E*, which is equally convex on both sides, and pass through it, they will be so refracted, as to meet in a

LECT. VII. point or principal focus f, whose distance is equal to the radius or semidiameter of the sphere of the glass's convexity. But if a glass be more convex on one side than on the other, the rule for finding the focal distance is this: as the sum of the semidiameters of both convexities is to the semidiameter of either, so is double the semidiameter of the other to the distance of the focus. Or, divide the double product of the radii by their sum, and the quotient will be the distance sought.

Since all those rays of the sun which pass through a convex glass are collected together in its focus, the force of all their heat is collected into that part; and is in proportion to the common heat of the sun, as the area of the glass is to the area of the focus. Hence we see the reason why a convex glass causes the sun's rays to burn after passing through it.

All these rays cross the middle ray in the focus f, and then diverge from it, to the contrary sides, in the same manner FfG, as they converged in the space DfE in coming to it.

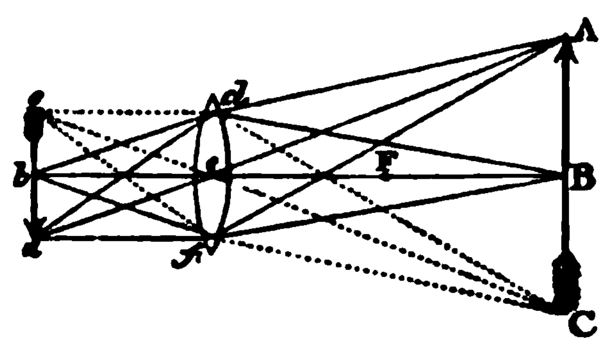
If another glass FG, of the same convexity as DE, be placed in the rays at the same distance from the focus, it will retract them so, as that after going out of it, they will be all parallel, as $a\,b\,c$, and go on in the same manner as they came to the first glass DE, through the space $A\,B\,C$; but on the contrary sides of the middle ray Bfb: for the ray $A\,Df$ will go on from f in the direction fGa, and the ray $C\,Ef$ in the direction fFc; and so of the rest.

The rays diverge from any radiant point, as from a principal focus: therefore, if a candle be placed at f, in the focus of the convex glass FG, the diverging rays in the space FfG will be so refracted by the glass, as, that after going out of it, they will become parallel, as shewn in the space $c\,b\,a$.

If the candle be placed nearer the glass than its focal distance, the rays will diverge after passing

through the glass, more or less, as the candle is more or less distant from the focus. LECT. VII.

If the candle be placed farther from the glass than its focal distance, the rays will converge after passing through the glass, and meet in a point which will be more or less distant from the glass, as the candle is nearer to, or farther from its focus; and where the rays meet, they will form an inverted image of the flame of the candle; which may be seen on a paper placed in the meeting of the rays.



Hence, if any object *ABC* be placed beyond the focus *F* of the convex glass *def*, some of the rays which flow from every point of the object, on the side next the glass, will fall upon it, and, after passing through it, they will be converged into as many points on the opposite side of the glass, where the image of every point will be formed: and consequently, the image of the whole object, which will be inverted. Thus, the rays *A d*, *A e*, *A f*, flowing from the point *A*, will converge in the space *d a f*, and by meeting at *a*, will there form the image of the point *A*. The rays *B d*, *B e*, *B f*, flowing from the point *B*, will be united at *b* by the refraction of the glass, and will there form the image of the point *B*. And the rays *C d*, *C e*, *C f*, flowing from the point *C*, will be united at *c*, where they will form the image of the point *C*. And so of all the other intermediate points between *A* and *C*. The rays which flow from every particular point of the object, and are united again by the glass, are called, *pencils of rays*.

If the object *A B C* be brought nearer to the glass, the picture *a b c* will be removed to a greater distance. For then, more rays flowing from every single point, will fall more diverging upon the glass; and therefore

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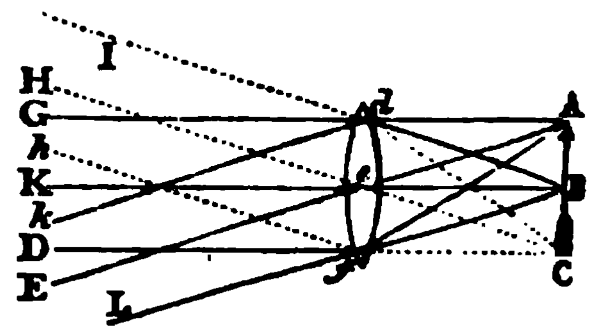
cannot be so soon collected into the corresponding points behind it. Consequently, if the distance of the object *A B C* be equal to the distance *e B* of the focus of the glass, the rays of each pencil will be so refracted by passing through the glass, that they will go out of it parallel to each other; as *d I*, *e H*, *f h*, from the point *C*; *d G*, *e K*, *f D*, from the point *B*; and *d K*, *e E*, *f L*, from the point *A*; and therefore, there will be no picture formed behind the glass.



If the focal distance of the glass, and the distance of the object from the glass, be known, the distance of the picture from the glass may be found by this rule, viz. multiply the distance of the focus by the distance of the object, and divide the product by their difference; the quotient will be the distance of the picture.

The picture will be as much bigger or less than the object, as its distance from the glass is greater or less than the distance of the object. For, as *B e* (in engraving, page 237.) is to *e b*, so is *A C* to *c a*. So that if *A B C* be the object, *c b a* will be the picture; or, if *c b a* be the object, *A B C* will be the picture.

The manner of vision.

Having described how the rays of light, flowing from objects and passing through convex glasses, are collected into points, and form the images of the objects; it will be easy to understand how the rays are affected by passing through the humours of the eye, and are thereby collected into innumerable points on the bottom of the eye, and thereon form the images of the objects which they flow from. For, the different humours of the eye, and particularly the chrystalline humour, are to be considered as a convex glass; and the rays in passing through them to be affected in the same manner as in passing through a convex glass.

The eye is nearly globular. It consists of three coats and three humours. The part *D H H G* of the outer

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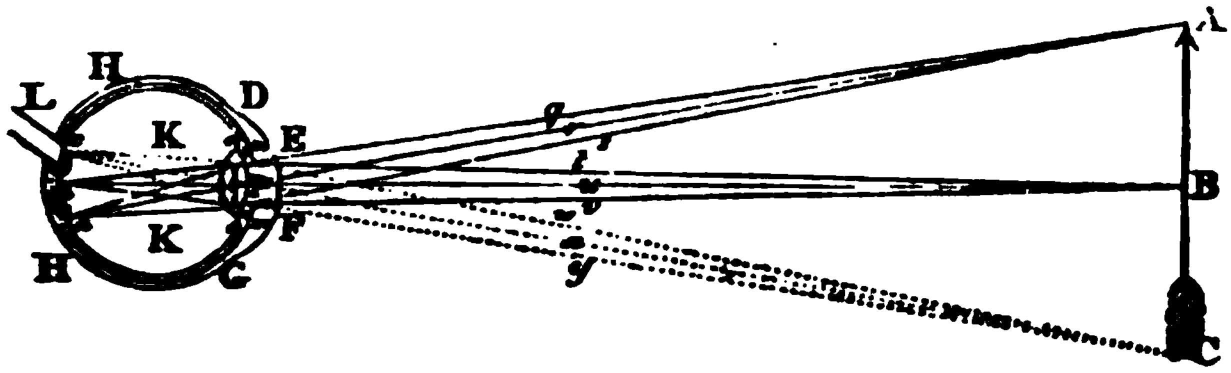


coat, is called the *sclerotica*, the rest *D E F G* the *cornea*. Next within this coat is that called the *choroides*, which serves as it were for a lining to the other, and joins with the *iris m n, m n*. The *iris* is composed of two sets of muscular fibres; the one of a circular form, which contracts the whole in the middle called the *pupil*, when the light would otherwise be too strong for the eye; and the other of radial fibres, tending every where from the circumference of the iris towards the middle of the pupil; which fibres, by their contraction, dilate and enlarge the pupil when the light is weak, in order to let in the more of its rays. The third coat is only a fine expansion of the optic nerve *L*, which spreads like net-work all over the inside of the choroides, and is therefore called the *retina*; upon which are painted (as it were) the images of all visible objects by the rays of light which either flow to, or are reflected from them.

The eye described.

Under the *cornea* is a fine transparent fluid like water, which is therefore called the *aqueous humour*. It gives a protuberant figure to the cornea, fills the two cavities *m m* and *n n*, which communicate by the pupil *P*, and has the same limpidity, specific gravity, and refractive power as water. At the back of this lies the *chrystalline humour I I*, which is shaped like a double convex glass; and is a little more convex on the back than the forepart. It converges the rays, which pass through it from every visible object to its focus at the bottom of the eye.

LECT. VII. This humour is transparent like crystal, is much of the consistence of hard jelly, and exceeds the specific gravity of water in the proportion of 11 to 10. It is enclosed in a fine transparent membrane, from which proceed radial fibres *o o*, called the *ligamentum ciliare*, all around its edge; and join to the circumference of the iris. These fibres have a power of contracting and dilating occasionally, by which means they alter the shape or convexity of the chrystalline humour, and also shift it a little backward or forward in the eye, so as to adapt its focal distance to the bottom of the eye to the different distances of objects; without which provision, we could only see those objects distinctly, that were all at one distance from the eye.

At the back of the chrystalline, lies the *vitreous humour K K*, which is transparent like glass and is largest of all in quantity, filling the whole orb of the eye, and giving it a globular shape. It is much of the consistence of the white of an egg, and very little exceeds the specific gravity and refractive power of water.

As every point of an object *A B C* sends out rays in all directions, some rays, from every point on the side next the eye, will fall upon the cornea between *E* and *F*; and by passing on through the humours and pupil of the eye, they will be converged to as many points on the retina or bottom of the eye, and will thereon form a distinct inverted picture *c b a* of the object. Thus, the pencil of rays *q r s* that flows from the point *A* of the object, will be converged to the point *a* on the retina; those from the point *B* will be converged to the point *b*; those from the point *C* will be converged to the point *c*; and so of all the intermediate points: by which means the whole image *a b c* is formed, and the object made visible; although it must be owned, that the method by which this sensation is carried from the eye by the optic nerve to the common sensory in the brain, and there discerned, is above the reach of our comprehension.

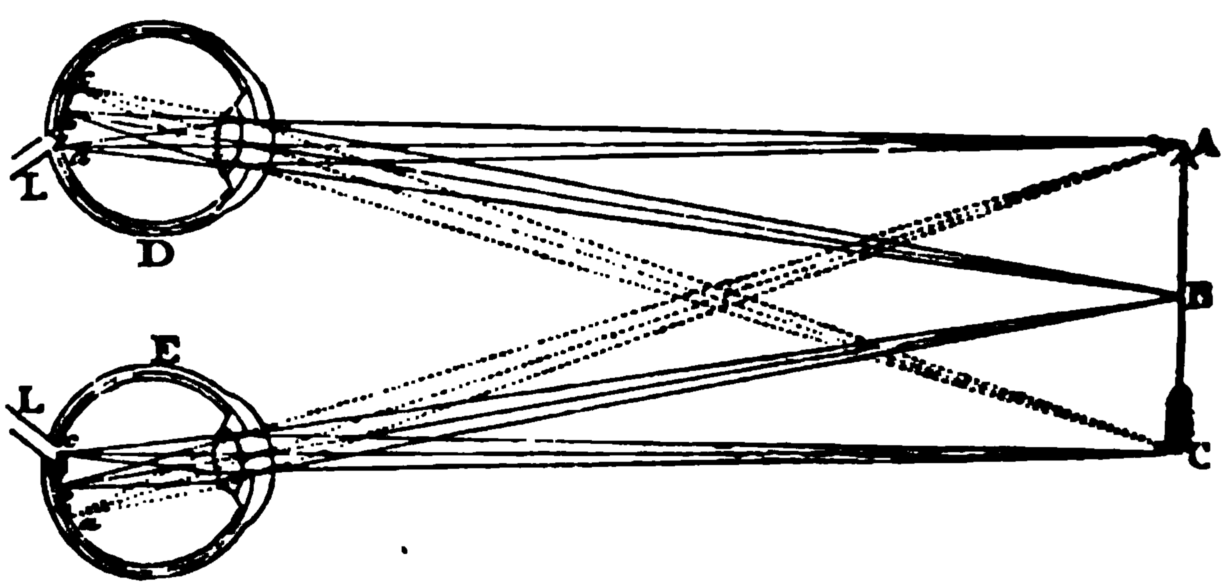
But, that vision is effected in this manner, may be demonstrated experimentally. Take a bullock's eye whilst it is fresh, and having cut off the three coats from the back part, quite to the vitreous humour, put a piece of white paper over that part, and hold the eye towards any bright object, and you will see an inverted picture of the object upon the paper.

Seeing the image is inverted, many have wondered why the object appears upright. But we are to consider, 1. That *inverted* is only a relative term; and 2. That there is a very great difference between the real object and the means or image by which we perceive it. When all the parts of a distant prospect are painted upon the retina, they are all right with respect to one another, as well as the parts of the prospect itself; and we can only judge of an object's being inverted, when it is turned reverse to its natural position, with respect to other objects which we see and compare it with.—If we lay hold of an upright stick in the dark, we can tell which is the upper or lower part of it, by moving our hand upward or downward; and know very well that we cannot feel the upper end by moving our hand downward. Just so we find by experience, that upon directing our eyes towards a tall object, we cannot see its top by turning our eyes downward, nor its foot by turning our eyes upward; but must trace the object the same way by the eye to see it from head to foot, as we do by the hand to feel it; and as the judgment is informed by the motion of the hand in one case, so it is also by the motion of the eye in the other.

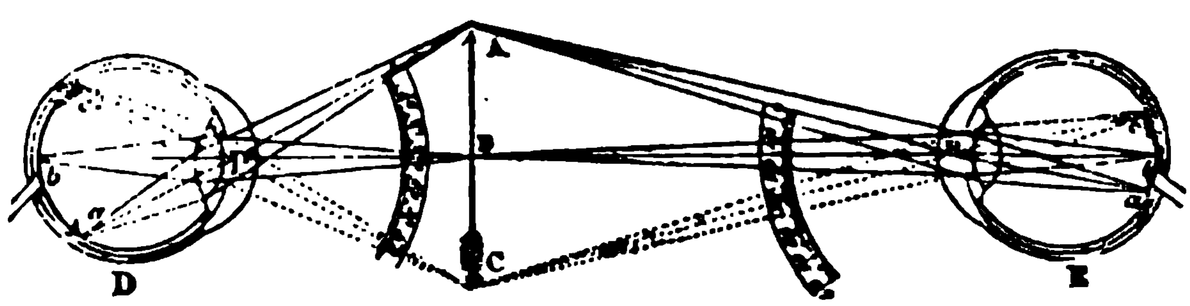
In the following diagram is exhibited the manner of seeing the same object *A B C*, by both the eyes *D* and *E* at once.

When any part of the image *c b a* falls upon the optic nerve *L*, the corresponding part of the object becomes invisible On which account nature has wisely placed the optic nerve of each eye, not in the middle of

LECT. VII.



the bottom of the eye, but towards the side next the nose; so that whatever part of the image falls upon the optic nerve of one eye, may not fall upon the optic nerve of the other. Thus the point *a* of the image *c b a* falls upon the optic nerve of the eye *D*, but not of the eye *E*; and the point *e* falls upon the optic nerve of the eye *E*, but not of the eye *D*: and therefore to both eyes taken together, the whole object *A B C* is visible.

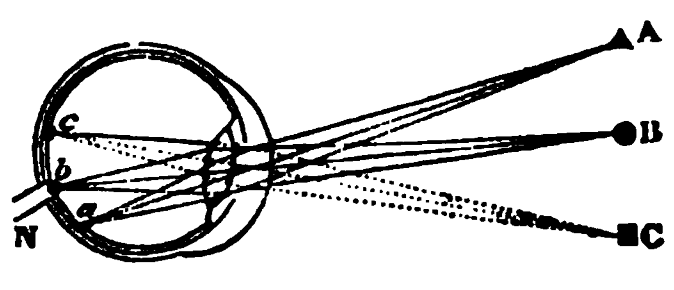


The nearer that any object is to the eye, the larger is the angle under which it is seen, and the magnitude under which it appears. Thus to the eye *D*, the object *A B C* is seen under the angle *A P C*; and its image *c b a* is very large upon the retina: but to the eye *E*, at a double distance, the same object is seen under the angle *A p C*, which is equal only to half the angle *A P C*, as is evident by the figure. The image *c b a* is likewise twice as large in the eye *D*, as the other image *c b a*, is in the eye *E*. In both these representations, a part of the image falls on the optic nerve, and the object in the corresponding part is invisible.

As the sense of seeing is allowed to be occasioned by

the impulse of the rays from the visible object upon the retina of the eye, and forming the image of the object thereon, and that the retina is only the expansion of the optic nerve all over the choroides; it should seem surprising, that the part of the image which falls on the optic nerve should render the like part of the object invisible; especially as that nerve is allowed to be the instrument by which the impulse and image are conveyed to the common sensory in the brain. But this difficulty vanishes, when we consider that there is an artery within the trunk of the optic nerve, which entirely obscures the image in that part, and conveys no sensation to the brain.

That the part of the image which falls upon the middle of the optic nerve is lost, and consequently the corresponding part of the object is rendered invisible, is plain by experiment. For, if a person fixes three patches, *A*, *B*, *C*, upon a white wall, at the height of the eye, and the distance of about a foot from each other, and places himself before them, shutting the right eye, and directing the left towards the patch *C*, he will see the patches *A* and *C*, but the middle patch *B* will disappear. Or, if he shuts his left eye, and directs the right towards *B*, he will see both *A* and *C*, but *B* will disappear; and if he directs his eye towards *B*, he will see both *B*, and *A*, but not *C*. For whatever patch is directly opposite to the optic nerve *N*, vanishes. This requires a little practice after which he will find it easy to direct his eye, so as to lose the sight of whichever patch he pleases.



We are not commonly sensible of this disappearance, because the motions of the eye are so quick and instantaneous, that we no sooner lose the sight of any part of an object, than we recover it again; much the same as in the twinkling of our eyes, for at each twinkling we are

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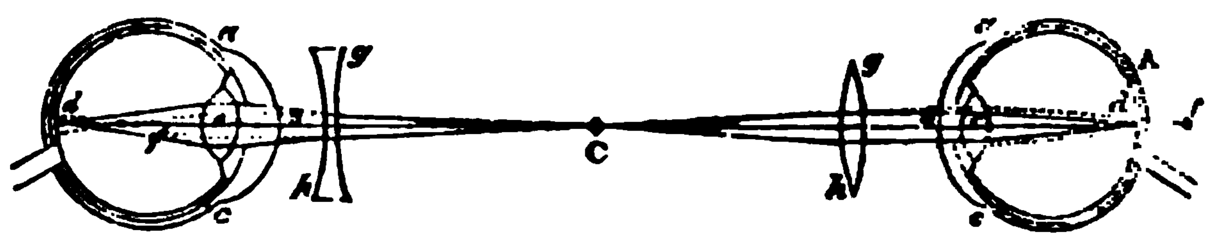
blinded; but it is so soon over, that we are scarce ever sensible of it.

Why some eyes require spectacles.

Some eyes require the assistance of convex glasses to make them see objects distinctly, and others of concave. If either the cornea *a b c* or chrystalline humour *e*, or



both of them, be too flat, as in the eye *A*, their focus will not be on the retina, as at *d*, where it ought to be in order to render vision distinct; but beyond the eye, as at *f*. Consequently those rays which flow from the object *C*, and pass through the humours of the eye, are not converged enough to unite at *d*; and therefore the observer can have but a very indistinct view of the object. This is remedied by placing a convex glass *g h* before the eye, which makes the rays converge sooner, and imprints the image duly on the retina at *d*.

If either the cornea, or chrystalline humour, or both of them, be too convex, as in the eye *f*, the rays that enter in from the object *C*, will be converged to a focus in the vitreous humour, as at *f*; and by diverging from thence to the retina, will form a very confused image thereon: and so, of course, the observer will have as confused a view of the object, as if his eye had been too flat. This inconvenience is remedied by placing a concave glass *g h* before the eye; which glass, by causing the rays to diverge between it and the eye, lengthens the focal distance so, that if the glass be properly chosen, the rays will unite at the retina, and form a distinct picture of the object upon it.

Such eyes as have their humours of a due convexity cannot see any object distinctly at a less distance than six inches; and there are numberless objects too small to be seen at that distance, because they cannot appear

under any sensible angle. The method of viewing such minute objects is by a *microscope*, of which there are three sorts viz. the *single*, the *double*, and the *solar*.

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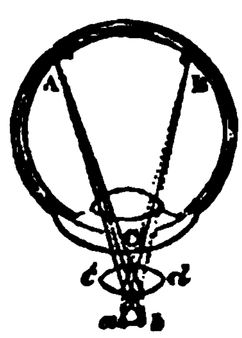
The single microscope.

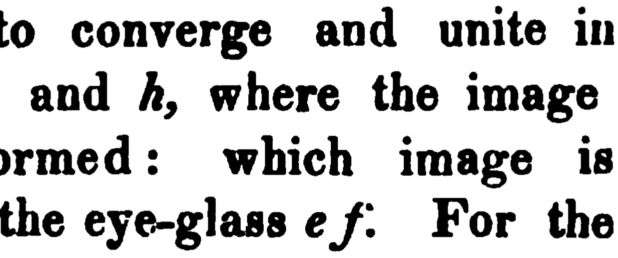
The *single microscope* is only a small convex glass, as *c d*, having the object *a b* placed in its focus, and the eye at the same distance on the other side; so that the rays of each pencil, flowing from every point of the object on the side next the glass, may go on parallel in the space between the eye and the glass; and then by entering the eye at *C*, they will be converged to as many different points on the retina, and form a large inverted picture *A B* upon it, as in the figure.



To find how much this glass magnifies, divide the least distance (which is about six inches) at which an object can be seen distinctly with the bare eye, by the focal distance of the glass; and the quotient will shew how much the glass magnifies the diameter of the object.

The double microscope.

The *double* or *compound microscope*, consists of an object-glass *c d*, and an eye-glass *e f*. The small object *a b* is placed at a little greater distance from the glass *c d* than its principal focus, so that the pencils of rays flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed: which image is viewed by the eye through the eye-glass *e f*. For the eye-glass being so placed, that the image *g h* may be in its focus, and the eye much about the same distance on the other side, the rays of each pencil will be parallel, after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k* where they will begin to converge by the refractive power of the humours; and af-

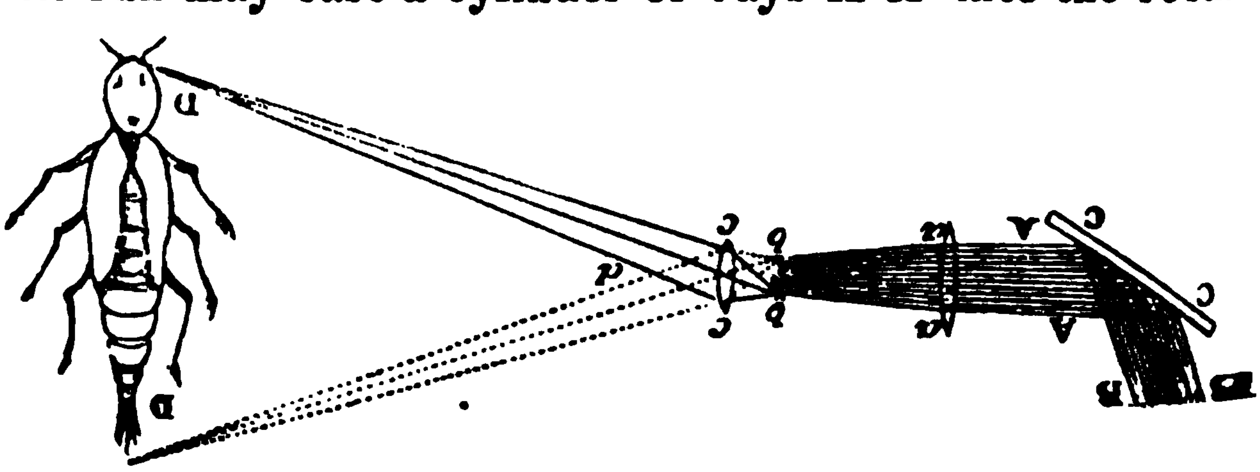


LECT. VII. ter having crossed each other in the pupil, and passed through the chrystalline and vitreous humours they will be collected into points on the retina, and form the large inverted image *A B* thereon.

The magnifying power of this microscope is as follows. Suppose the image *g h* to be six times the distance of the object *a b* from the object-glass *c d;* then will the image be six times the length of the object: but since the image could not be seen distinctly by the bare eye at a less distance than six inches, if it be viewed by an eye-glass *e f*, of one inch focus, it will thereby be brought six times nearer the eye, and consequently viewed under an angle six times as large as before; so that it will be again magnified six times; that is, six times by the object-glass, and six times by the eye-glass, which multiplied into one another, makes 36 times; and so much is the object magnified in diameter more than what it appears to the bare eye; and consequently 36 times 36, or 1296 times in surface.

But, because the extent or field of view is very small in this microscope, there are generally two eye-glasses placed sometimes close together, and sometimes an inch asunder; by which means, although the object appears less magnified, yet the visible area is much enlarged by the interposition of a second eye-glass: and consequently a much pleasanter view is obtained.

The *solar microscope.* The *solar microscope,* invented by *Dr. Lieberkhun,* is constructed in the following manner. Having procured a very dark room, let a round hole be made in the window-shutter, about three inches diameter, though which the sun may cast a cylinder of rays *A A* into the room.



In this hole, place the end of a tube, containing two convex glasses and an object, viz. 1. A convex glass *a a*, of about two inches diameter, and three inches focal distance, is to be placed in that end of the tube which is put into the hole. 2. The object *b b*, being put between two glasses (which must be concave to hold it at liberty) is placed about two inches and a half from the glass *a a*. 3. A little more than a quarter of an inch from the object is placed the small convex glass *c c*, whose focal distance is a quarter of an inch.

The tube may be so placed, when the sun is low, that his rays *A A* may enter directly into it: but when he is high, his rays *B B* must be reflected into the tube by the plane mirror or looking-glass *C C*.

Things being thus prepared, the rays that enter the tube will be conveyed by the glass *a a* towards the object *b b*, by which means it will be strongly illuminated; and the rays *d* which flow from it, through the magnifying glass *c c*, will make a large inverted picture of the object at *D D*, which, being received on a white paper, will represent the object magnified in length, in proportion of the distance of the picture from the glass *c c*, to the distance of the object from the same glass. Thus, suppose the distance of the object from the glass to be $\frac{3}{10}$ parts of an inch, and the distance of the distinct picture to be 12 feet or 144 inches, in which there are 1440 tenths of an inch; and this number divided by $\frac{3}{10}$, gives 480; which is the number of times the picture is longer or broader than the object; and the length multiplied by the breadth, shews how much the whole surface is magnified.[66]

Note 66. The simplest microscope which can be employed to any useful purpose is perhaps that which is made with a drop of water, suspended in a very small hole in a thin slip of brass, or any similar material. This may easily be constructed where no other microscope can be obtained, and its performance will be found very satisfactory. A spherule of water, it must be observed, of the same size as one of glass, will not magnify so much as the latter, because, as its density is not so great,

LECT. VII.

Telescopes.

Before we enter upon the description of telescopes, it will be proper to shew how the rays of light are af-

it has a longer focus. A small drop or spherule of water, held to the eye by candle light or moonlight, without any other apparatus, magnifies in a very surprising manner the animalculæ contained in it. The reason is, that the rays, coming from the interior surface of the first hemisphere, are reflected so as to fall under the same angle on the surface of the posterior hemisphere, to which the eye is applied, as if they came from the focus of the spherule; whence they are propagated to the eye in the same manner as if the objects were placed without the spherule in its focus.

These water microscopes have given rise to the use of other fluids, with several varieties of construction. Dr. Brewster has described one in which he makes use of very pure and viscid turpentine. This he takes up by the point of a piece of wood, and drops successively upon a thin and well-polished glass: different quantities being thus taken up and dropped in a similar manner, form four or more plano-convex lenses of turpentine varnish, which may be made of any focal length, by taking up a greater or less quantity of the fluid. The lower surface of the glass having been first smoked with a candle, the black pigment below the lenses is then to be removed, so that no light may pass by their circumference. The piece of glass is then to be perforated, and surrounded with a toothed wheel, which can be moved round the hole as a center by an endless screw. The apparatus is then placed in a circular case, and this case fixed to a horizontal arm by means of a brass pin, which passes through its upper and under surfaces, and through the hole already mentioned, which does not embrace the pin very tightly, in order that the toothed wheel may revolve with facility. On the upper surface of the circular case is an aperture directly above the line described by the centers of the fluid lenses, when moving round the central hole; and in this aperture is inserted a small cap, with a little hole at its top, to which the eye is applied. A moveable stage carries the slider, on which microscopic objects are laid, and is brought nearer or removed from the lenses by a vertical screw. The objects on the slider are illuminated by a plane mirror, which has both a vertical and horizontal motion for this purpose. When the microscope is thus constructed, the object to be viewed is placed upon the slider, and the endless screw is turned till one of the lenses be directly under the aperture; and the slider is then raised or depressed by the vertical screw, till the object be brought into the focus of the lens. In this manner, by turning the endless screw, and bringing all the lenses, one after another, directly below the aperture, the object may be successively examined with a variety of magnifying powers. These fluid lenses have been employed as the object-glasses of compound microscopes.

Minute glass spherules make very excellent microscopes, to those who have a little patience in using such instruments; for the foci of the

fected by passing through concave glasses, and also by falling upon concave mirrors.

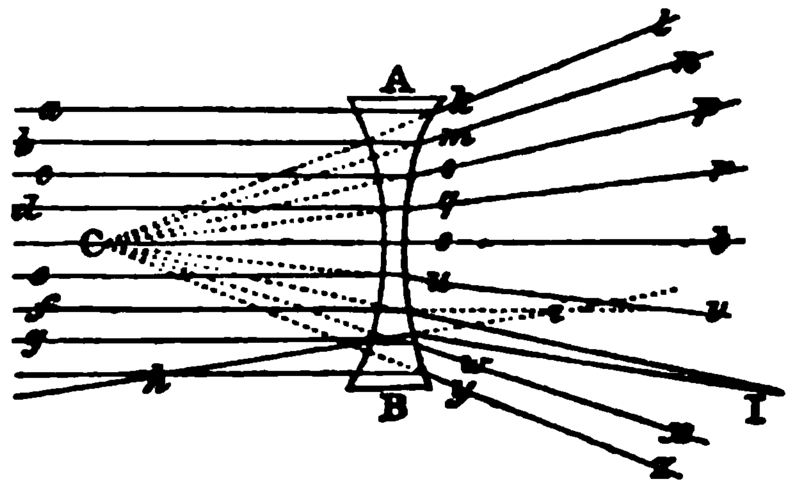
smallest sort are so short, that it requires considerable attention to employ them well. F. Di Torre, of Naples, in 1765, sent several glass globules to the Royal Society. The largest of them was only two Paris points in diameter, and is said to magnify the diameter of an object 640 times; another was the size of one Paris point, magnifying the diameter 1280 times; and the smallest no more than one half of a Paris point, or the 144th part of an inch in diameter, and is said to magnify the diameter of an object 2560 times; and consequently the square of that diameter 6,553,600 times. Globules so exceedingly minute as these, were at one time highly prized, but spherule microscopes are not now made so small, to avoid straining the eyes. The third, or smallest globule above-mentioned, could only be the 576th part of an inch distant from the object, because the focus of a glass globe is at the distance of one-fourth of its diameter; it is obvious therefore that it could admit very little light, and could not be used without pain and difficulty even by practised observers.

Of the various methods which have been recommended for making glass spherules, the following by Nicholson is perhaps the best. It is observed by this valuable practical writer, that the usual method has been to draw out a fine thread of the soft white glass called crystal, and to convert the extremity of this into a spherule by melting it at the flame of a candle. But this glass contains lead, which is disposed to become opaque by partial reduction, unless the management be very carefully attended to. He found that the hard glass used for windows seldom fails to afford excellent spherules. This glass is of a clear bright green when seen edgeways. A thin piece, less than one-tenth of an inch broad, was cut from the edge of a pane of glass. This was held perpendicularly by the upper end, and the flame of a candle was directed upon it by the blow-pipe, at the distance of about an inch from the lower end. The glass became soft, and the lower piece descended by its own weight to the distance of about two feet, where it remained suspended by a thin thread of glass, about ...th of an inch in diameter. A part of this thread was applied endways to the lower blue flame of the candle, without the use of the blow-pipe. The extremity immediately became white, and formed a globule. The glass was then gradually and regularly thrust towards the flame, but never into it, until the globule was sufficiently large. A number of these were made, and being afterwards examined by viewing their focal images with a deep magnifier, proved very bright, round, and perfect.

Spherules are mounted for use by placing them between two very thin plates of brass, each containing a small hole rather less than themselves. If any imperfection in the globule is discoverable, it is placed on one side, so that it may be covered by the plates. The objects may be placed on the point of a needle, the direction of which should be at right angles to the axis of the eye, to prevent accidents.

LECT. VII.

When parallel rays, as *a b c d e f g h*, pass directly



through a glass *A B*, which is equally concave on both sides, they will diverge after passing through the glass, as if they had come from a radiant point *C*, in the center of the glass's concavity; which point is called the negative or virtual focus of the glass. Thus the ray *a*, after passing through the glass *A B*, will go on in the direction *k l*, as if it had proceeded from the point *C*, and no glass been in the way. The ray *b* will go on in

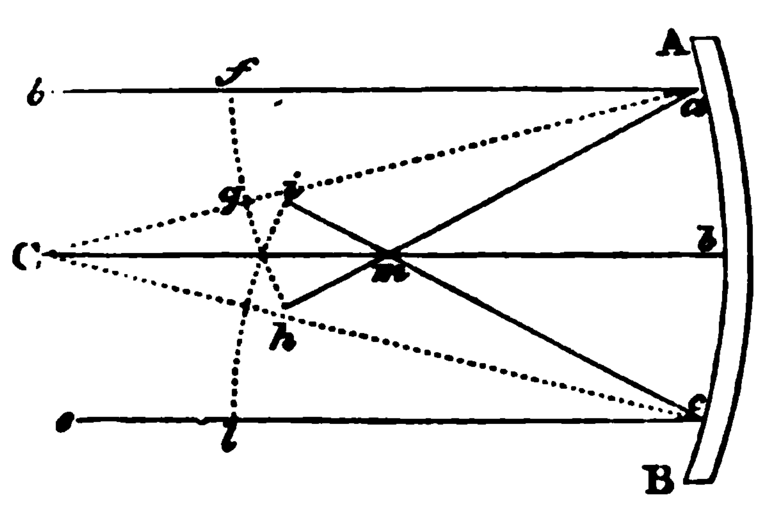
Dr. Wollaston has proposed an improvement in microscopes, which he thinks highly advantageous. The great desideratum, he observes, in employing high magnifiers, is sufficiency of light; and it is accordingly expedient to make the aperture of the little lens as large as is consistent with distinct vision. But if the object to be viewed is of such magnitude as to appear under an angle of several degrees on each side of the center, the requisite distinctness cannot be given to the whole surface by a common lens, in consequence of the confusion occasioned by the oblique incidence of the lateral rays, excepting by means of a very small aperture, and proportionable diminution of light. In order to remedy this inconvenience, he used two plano-convex lenses, ground to the same radius, and applied their plane surfaces on opposite sides of the same aperture in a thin piece of metal. Thus he virtually obtained a double convex lens, with this advantage, that the passage of oblique rays was at right angles with the surfaces as well as the central pencil. With a lens so constructed, the perforation that appeared to give the most perfect distinctness, was about one-fifth part of the focal length in diameter, and when such an aperture is well centred, the visible field is at least as much as twenty degrees in diameter. It is true, that a portion of light is lost by doubling the number of surfaces, but this is more than compensated by the greater aperture which, under these circumstances, is compatible with distinct vision.

the direction *m n*; the ray *c* in the direction *o p*, &c.— The ray *C*, that falls directly upon the middle of the glass, suffers no refraction in passing through it; but goes on in the same rectilineal direction, as if no glass had been in its way. LECT. VII.

If the glass had been concave only on one side, and the other side quite plane, the rays would have diverged, after passing through it, as if they had come from a radiant point at double the distance of *C* from the glass; that is, as if the radiant point had been at the distance of a whole diameter of the glass's concavity.

If rays come more converging to such a glass, than parallel rays diverge after passing through it, they will continue to converge after passing through it; but will not meet so soon as if no glass had been in the way; and will incline towards the same side to which they would have diverged, if they had come parallel to the glass. Thus the rays *f* and *h*, going in a converging state towards the edge of the glass at *B*, and converging more in their way to it than the parallel rays diverge after passing through it, they will go on converging after they pass through it, though in a less degree than they did before, and will meet at *I*: but if no glass had been in their way, they would have met at *i*.

When the parallel rays as *d f a*, *C m b*, *e l c*, fall upon



a concave mirror *A B*, (which is not transparent, but has only the surface *A b B* of a clear polish) they will

LECT. VII. be reflected back from that mirror, and meet in a point *m*, at half the distance of the surface of the mirror from *C*, the center of its concavity: for they will be reflected at as great an angle from the perpendicular to the surface of the mirror, as they fell upon it, with regard to that perpendicular; but on the other side thereof. Thus, let *C* be the center of concavity of the mirror *A b B*, and let the parallel rays *d f a*, *C m b*, and *e l c*, fall upon it at the points *a*, *b*, and *c*. Draw the lines *C i a*, *C m b*, and *C h c*, from the center *C* to these points; and all these lines will be perpendicular to the surface of the mirror, because they proceed thereto like so many *radii* or spokes from its center. Make the angle *C a h* equal to the angle *d a C*, and draw the line *a m h*, which will be the direction of the ray *d f a*, after it is reflected from the point *a* of the mirror: so that the angle of incidence *d a C*, is equal to the angle of reflection *C a h;* the rays making equal angles with the perpendicular *C i a* on its opposite sides.

Draw also the perpendicular *C h c* to the point *c*, where the ray *e l c* touches the mirror; and, having made the angle *C c i* equal to the angle *C c e*, draw the line *c m i*, which will be the course of the ray *e l c*, after it is reflected from the mirror.

The ray *C m b* passes through the center of concavity of the mirror, and falls upon it at *b*, the perpendicular to it; and is therefore reflected back from it in the same line *b m C*.

All these reflected rays meet in the point *m;* and in that point the image of the body which emits the parallel rays *d a*, *C b*, and *e c*, will be formed: which point is distant from the mirror equal to half the radius *b m C* of its concavity.

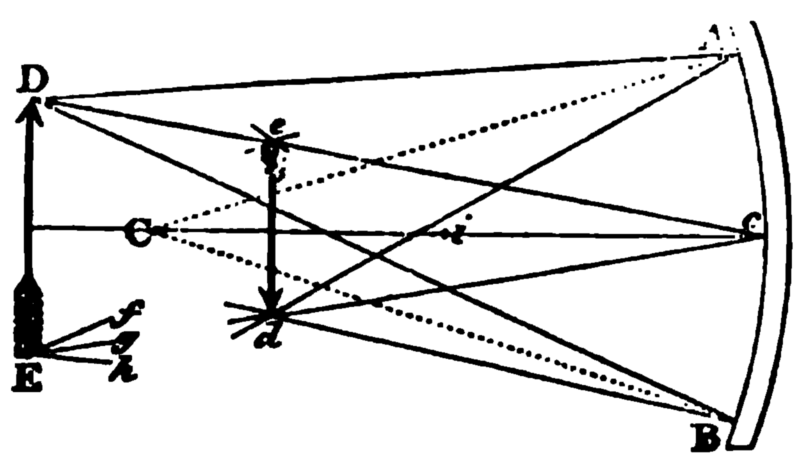
The rays which proceed from any celestial object may be esteemed parallel at the earth; and therefore the images of that object will be formed at *m*, when the reflecting surface of the concave mirror is turned di-

LECT. VII.

rectly towards the object. Hence, the focus *m* of parallel rays is not in the center of the mirror's concavity, but half way between the mirror and that center.

The rays which proceed from any remote terrestrial object are nearly parallel at the mirror; not strictly so, but come diverging to it, in separate pencils, or, as it were, bundles of rays, from each point of the side of the object next the mirror: and therefore, they will not be converged to a point, at the distance of half the radius of the mirror's concavity from its reflecting surface; but into separate points at a little greater distance from the mirror. And the nearer the object is to the mirror, the farther these points will be from it; and an inverted image of the object will be formed in them, which will seem to hang pendent in the air; and will be seen by an eye placed beyond it (with regard to the mirror) in all respects like the object, and as distinct as the object itself.

Let *A c B* be the reflecting surface of a mirror,



whose center of concavity is at *C*; and let the upright object *D E* be placed beyond the center *C*, and send out a conical pencil of diverging rays from its upper extremity *D*, to every point of the concave surface of the mirror *A c B*. But, to avoid confusion, we only draw three rays of that pencil, as *D A*, *D c*, *D B*.

From the center of concavity *C*, draw the three right lines *C A*, *C c*, *C B*, touching the mirror in the same points where the aforesaid rays touch it; and all these

LECT. VII. lines will be perpendicular to the surface of the mirror. Make the angle *C A d* equal to the angle *D A C*, and draw the right line *A d* for the course of the reflected ray *D A*: make the angle *C c d* equal to the angle *D c C*, and draw the right line *c d* for the course of the reflected ray *D d*: make also the angle *C B d* equal to the angle *D B C*, and draw the right line *B d*, for the course of the reflected ray *D B*. All these reflected rays will meet in the point *d*, where they will form the extremity *d* of the inverted image *e d*, similar to the extremity *D* of the object *D E*.

If the pencils of rays *E f*, *E g*, *E h*, be also continued to the mirror, and their angles of reflection from it be made equal to their angles of incidence upon it, as in the former pencil from *D*, they will all meet at the point *e* by reflection, and form the extremity *e* of the image *e d*, similar to the extremity *E* of the object *D E*.

And as each intermediate point of the object, between *D* and *E*, sends out a pencil of rays in like manner to every part of the mirror, the rays of each pencil will be reflected back from it, and meet in all the intermediate points between the extremities *e* and *d* of the image; and so the whole image will be formed, not at *i*, half the distance of the mirror from its center of concavity *C*; but at a greater distance, between *i*, and the object *D E*; and the image will be inverted with respect to the object.

This being well understood, the reader will easily see how the image is formed by the large concave mirror of the reflecting telescope, when he comes to the description of that instrument.

When the object is more remote from the mirror than its center of concavity *C*, the image will be less than the object, and between the object and mirror: when the object is nearer than the center of concavity, the image will be more remote and bigger than the object: thus, if *D E* be the object, *e d* will be the image; for, as the object

recedes from the mirror, the image approaches nearer to it; and, as the object approaches nearer to the mirror, the image recedes farther from it; on account of the lesser or greater divergency of the pencils of rays which proceed from the object; for, the less they diverge, the sooner they are converged to points by reflection; and the more they diverge, the farther they must be reflected before they meet.

If the radius of the mirror's concavity and the distance of the object from it be known, the distance of the image from the mirror is found by this rule: divide the product of the distance and radius by double the distance made less by the radius, and the quotient is the distance required.

If the object be in the center of the mirror's concavity, the image and object will be coincident, and equal in bulk.

If a man places himself directly before a large concave mirror, but farther from it than its center of concavity, he will see an inverted image of himself in the air, between him and the mirror, of a less size than himself. And if he holds out his hand towards the mirror, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk, when his hand is in the center of concavity; and he will imagine he may shake hands with his image. If he reaches his hand farther, the hand of the image will pass by his hand, and come between his hand and his body: and if he moves his hand towards either side, the hand of the image will move towards the other; so that whatever way the object moves, the image will move the contrary.[67]

Note 67. A very terrific spectacle has been exhibited, in which a hand grasping a dagger appears to strike those who approach the recess in which the mirror is placed. To produce this effect, the person on whom the deception is intended to be practised is made to approach armed with a polished weapon, and his body being illu-

LECT. VII. All the while a by-stander will see nothing of the image, because none of the reflected rays that form it enter his eyes.

If a fire be made in a large room, and a smooth mahogany table be placed at a good distance near the wall, before a large concave mirror, so placed that the light of the fire may be reflected from the mirror to its focus upon the table; if a person stands by the table, he will see nothing upon it but a longish beam of light: but if he stands at a distance towards the fire, not directly between the fire and mirror, he will see an image of the fire upon the table, large and erect. And if another person, who knows nothing of this matter beforehand, should chance to come into the room, and should look from the fire towards the table, he would be startled at the appearance; for the table would seem to be on fire, and by being near the wainscot to endanger the whole house. In this experiment, there should be no light in the room but what proceeds from the fire; and the mirror ought to be at least fifteen inches in diameter.

If the fire be darkened by a screen, and a large candle be placed at the back of the screen; a person standing by the candle will see the appearance of a fine large star, or rather planet, upon the table, as bright as Venus or Jupiter. And if a small wax taper (whose flame is much less than the flame of the candle) be placed near the candle, a satellite to the planet will appear on the table: and if the taper be moved round the candle, the satellite will go round the planet.

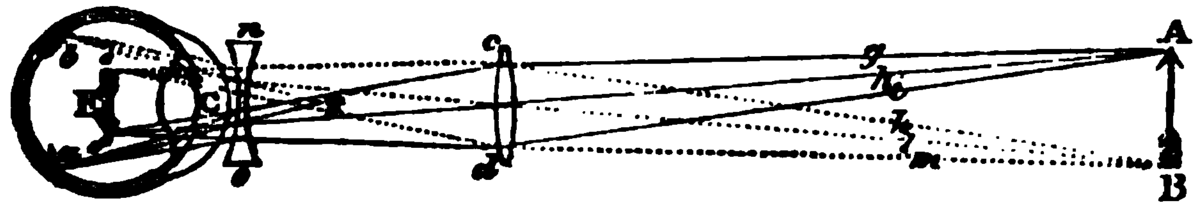
For these two pleasing experiments, I am indebted to the late Rev. Dr. LONG, *Lowndes's* professor of astronomy at Cambridge, who favoured me with the sight of them, and many more of his curious inventions.

In a *refracting telescope*, the glass which is nearest the object in viewing it, is called *the object-glass*; and that

minated by a strong light, while the mirror is in darkness, the dagger appears directed towards the heart of him who wields it.

which is nearest the eye, is called *the eye-glass*. The object-glass must be convex, but the eye-glass may be either convex or concave: and generally, in looking through a telescope, the eye is in the focus of the eye-glass; though that is not very material: for the distance of the eye, as to distinct vision, is indifferent, provided the rays of the pencils fall upon it parallel: only, the nearer the eye is to the end of the telescope, the larger is the scope or area of the field of view. LECT. VII.

Let *c d* be a convex glass fixed in a long tube, and



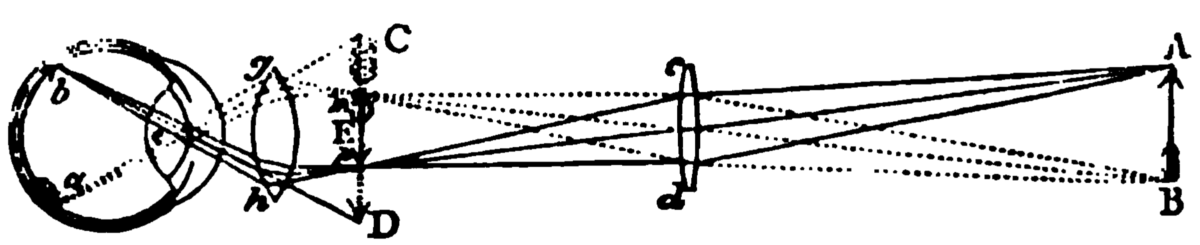
have its focus at *E*. Then, a pencil of rays *g h i*, flowing from the upper extremity *A* of the remote object *A B*, will be so refracted by passing through the glass, as to converge and meet in the point *f*; whilst the pencil of rays *k l m*, flowing from the lower extremity *B*, of the same object *A B*, and passing through the glass, will converge and meet in the point *e*: and the images of the points *A* and *B*, will be formed in the points *f* and *e*. And as all the intermediate points of the object between *A* and *B*, send out pencils of rays in the same manner, a sufficient number of these pencils will pass through the object-glass *c d*, and converge to as many intermediate points between *e* and *f*; and so will form the whole inverted image *e E f*, of the distinct object. But because this image is small, a concave glass *n o* is so placed in the end of the tube next the eye, that its virtual focus may be at *F*. And as the rays of the pencils pass converging through the concave glass, but converge less after passing through it than before, they go on further, as to *b* and *a*, before they meet; and the pencils themselves being made to diverge by passing through the concave glass, they enter the eye, and form the large

LECT. VII.

picture *a b* upon the retina, whereon it is magnified under the angle *b F a*.

But this telescope has one inconvenience which renders it unfit for most purposes, which is, that the pencils of rays being made to diverge by passing through the concave glass *n o*, very few of them can enter the pupil of the eye; and therefore the field of view is but very small, as is evident by the figure. For none of the pencils which flow either from the top or bottom of the object *A B* can enter the pupil of the eye at *C*, but are all stopped by falling upon the iris above and below the pupil: and therefore, only the middle part of the object can be seen when the telescope lies directly towards it, by means of those rays which proceed from the middle of the object. So that to see the whole of it, the telescope must be moved upwards and downwards, unless the object be very remote; and then it is never seen distinctly.

This inconvenience is remedied by substituting a convex eye-glass, as *g h* in place of the concave one; and



fixing it so in the tube, that its focus may be coincident with the focus of the object-glass *c d*, as at *E*. For then, the rays of the pencils flowing from the object *A B*, and passing through the object-glass *c d*, will meet in its focus, and form the inverted image *m E p*: and as the image is formed in the focus of the eye-glass *g h*, the rays of each pencil will be parallel, after passing through that glass; but the pencils themselves will cross in its focus, on the other side, as at *e*: and the pupil of the eye being in this focus, the image will be viewed through the glass, under the angle *g e h*; and being at *E*, it will appear magnified, so as to fill the whole space *C m e p D*.

But as this telescope inverts the image with respect to the object, it gives an unpleasant view of terrestrial objects; and is only fit for viewing the heavenly bodies, in which we regard not their position, because their being inverted does not appear, on account of their being round. But whatever way the object seems to move, this telescope must be moved the contrary way, in order to keep sight of it; for, since the object is inverted, its motion will be so too.

The magnifying power of this telescope is as the focal distance of the object-glass to the focal distance of the eye-glass. Therefore, if the former be divided by the latter, the quotient will express the magnifying power.

When we speak of the magnifying of a telescope or microscope, it is only meant with regard to the diameter, not to the area or solidity of the object. But as the instrument magnifies the vertical diameter, as much as it does the horizontal, it is easy to find how much the whole visible area or surface is magnified: for, if the diameters be multiplied into one another, the product will express the magnitude of the whole visible area. Thus, suppose the focal distance of the object-glass be ten times as great as the focal distance of the eye-glass, then, the object will be magnified ten times, both in length and breadth: and 10 multiplied by 10, produces 100; which shews that the area of the object will appear 100 times as big when seen through such a telescope, as it does to the bare eye.

Hence it appears, that if the focal distance of the eye-glass, were equal to the focal distance of the object-glass, the magnifying power of the telescope would be nothing.

This telescope may be made to magnify in any given degree, provided it be of a sufficient length. For, the greater the focal distance of the object-glass, the less may be the focal distance of the eye-glass; though not directly in proportion. Thus, an object-glass of 10

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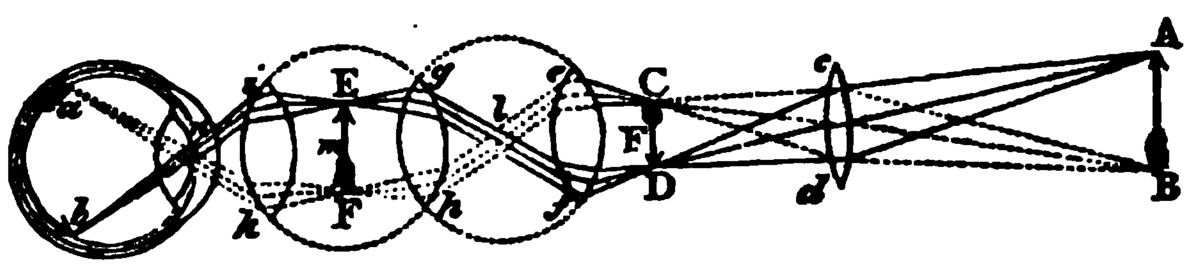
feet focal distance, will admit of an eye-glass whose focal distance is little more than 2½ inches; which will magnify nearly 48 times: but an object-glass of 100 feet focus will require an eye-glass somewhat more than 6 inches; and will therefore magnify almost 200 times.

A telescope for viewing terrestrial objects should be so constructed as to shew them in their natural posture. And this is done by one object-glass *c d*, and three eye-



glasses *e f*, *g h*, *i k*, so placed that the distance between any two, which are nearest to each other, may be equal to the sum of their focal distances; as in the figure, where the focus of the glasses *c d* and *e f* meet at *F*, those of the glasses *e f* and *g h*, meet at *l*, and of *g h* and *i k*, at *m*; the eye being at *n*, in or near the focus of the eye-glass *i k*, on the other side. Then, it is plain, that those pencils of rays, which flow from the object *A B*, and pass through the object-glass *c d*, will meet and form an inverted image *C F D* in the focus of that glass; and the image being also in the focus of the glass *e f*, the rays of the pencils will become parallel, after passing through that glass, and cross at *l*, in the focus of the glass *e f*; from whence they pass on to the next glass *g h*, and by going through it they are converged to points in its other focus, where they form an erect image *E m F*, of the object *A B*: and as this image is is also in the focus of the eye-glass *i k*, and the eye on the opposite side of the same glass; the image is viewed through the eye-glass in this telescope, in the same manner as through the eye-glass in the former one; only in a contrary position, that is, in the same position with the object.

The three glasses next the eye, have all their focal

distances equal: and the magnifying power of this telescope is found the same way as that of the last above; viz. by dividing the focal distance of the object-glass *c d*, by the focal distance of the eye-glass *i k*, or *g h*, or *e f*, since all these three are equal.

LECT. VII.

Why the object appears coloured when seen through a telescope.

When the rays of light are separated by refraction, they become coloured, and if they be united again, they will be a perfect white. But those rays which pass through a convex glass, near its edges are more unequally refracted than those which are nearer the middle of the glass. And when the rays of any pencil are unequally refracted by the glass, they do not all meet again in one and the same point, but in separate points; which makes the image indistinct, and coloured, about its edges. The remedy is, to have a plate with a small round hole in its middle, fixed in the tube at *m*, parallel to the glasses. For, the wandering rays about the edges of the glasses will be stopped by the plate from coming to the eye; and none admitted but those which come through the middle of the glass, or at least at a good distance from its edges, and pass through the hole in the middle of the plate. But this circumscribes the image, and lessens the field of view, which would be much larger if the plate could be dispensed with.[68]

Note 68. Before we dismiss the subject of refracting telescopes, it may be advisable to notice an ingenious combination of glasses now employed in all the best telescopes, by which the instrument is made to produce a colourless image, and, as such, divested of the prismatic tinge so justly complained of by the early observers. Mr. Dolland appears to have been the first who succeeded in effecting this desirable object, which he accomplished by employing a compound object-glass, formed of three lenses of different refractive powers. The central being a double concave glass, while the two external glasses may be considered perfect double convex lenses.

To proportion accurately the densities of the glasses to each other, requires much professional practice and attention. Experiments with the lenses, after they are perfectly finished, can alone be depended on. The essential parts of telescopes being few and cheap, the manufacture of them is frequently attempted by individuals for the purpose of

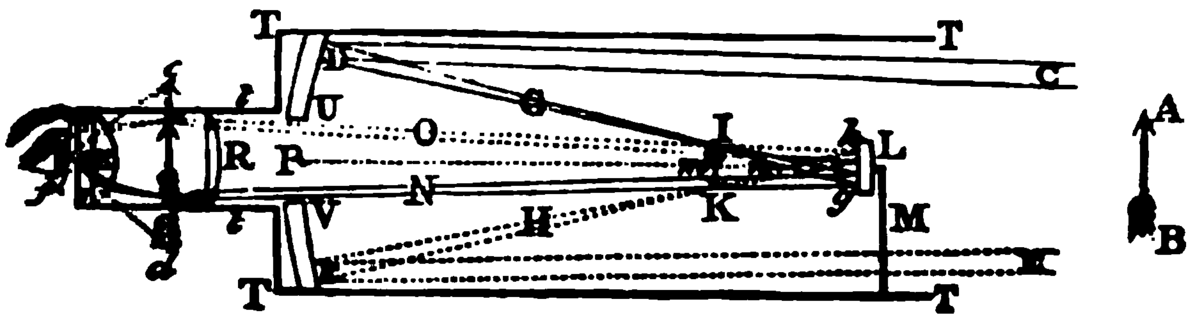
LECT. VII.

The reflecting telescope.

The great inconvenience attending the management of long telescopes of this kind, has brought them much into disuse ever since the *reflecting telescope* was invented. For one of this sort, six feet in length, magnifies as much as one of the other a hundred. It was invented by *Sir Isaac Newton*, but has received considerable improvement since his time; and is now generally constructed in the following manner, which was first proposed by *Dr. Gregory*.

amusement; and in every kind of telescope but the achromatic, they have, with a due degree of perseverance, a fair hope of success. But in attempting to form an achromatic object-glass, however well they may think they have selected their glass, and proportioned the curvatures of the surfaces, they will be almost certain to find that a single set of lenses, when combined, produce an effect that disappoints their expectations. To succeed perfectly, they must therefore make, from different parcels of glass, a considerable number of lenses, with slight differences of curvature, and those must be selected which will bear the largest aperture and magnifying power. But this would render the undertaking, for the sake of one or two instruments, an Herculean labour, which would not bring to any private individual an adequate recompence; and which, from the number of imperfect telescopes which are manufactured by those in the most extensive line of business, it would appear that opticians themselves do not fully enter into the spirit of. It has been very generally said and believed, that Dollond made his original experiments, and constructed those excellent three-foot glasses (which at present bear so high a price, and are considered as inimitable), with one single parcel of glass, which accidentally proved superior to any that has since been produced.—Nicholson has rendered it extremely probable that this is a vulgar error; the proprietor of the glass-house having assured him, that the original receipts and practice are still followed in the making of optical glass: that the principal opticians always complain of the bad quality of the glass, but never fail to take the whole quantity he makes at their request; and that, when they renew their orders, they always desire it may be exactly the same as the last. It seems therefore reasonable to conclude, that though different parcels of glass, made according to the same process, may differ a little, yet that as good glass for optical uses may be obtained now as formerly, and consequently as good telescopes, if the same great skill and disregard of expense which Dollond evinced, in adapting the curvatures of his lenses to each other and to the glass, were again resorted to.

At the bottom of the great tube *T T T T* is placed



the large concave mirror *D U V F*, whose principal focus is at *m;* and in its middle is a round hole *P*, opposite to which is placed the small mirror *L*, concave towards the great one ; and so fixed to a strong wire *M*, that it may be moved farther from the great mirror, or nearer to it, by means of a long screw on the outside of the tube, keeping its axis still in the same line *P m n* with that of the great one.—Now since, in viewing a very remote object, we can scarcely see a point of it but what is at least as broad as the great mirror, we may consider the rays of each pencil, which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting surface *D U V F.* But, to avoid confusion in the figure, we shall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progress, through all their reflections and refractions, to the eye *f*, at the end of the small tube *t t*, which is joined to the great one.

Let us then suppose the object *A B* to be at such a distance, that the rays *C* may flow from its lower extremity *B*, and the rays *E* from its upper extremity *A*. Then the rays *C*, falling parallel upon the great mirror at *D*, will be thence reflected, converging in the direction *D G;* and, by crossing at *I*, in the principal focus of the mirror, they will form the upper extremity *I* of the inverted image *I K*, similar to the lower extremity *B*, of the object *A B*: and passing on to the concave mirror *L* (whose focus is at *n*) they will fall upon it at

LECT. VII. *g*, and be thence reflected converging, in the direction *g N*, because *g m* is longer than *g n*; and passing through the hole *P* in the large mirror, they would meet somewhere about *r*, and form the lower extremity *d* of the erect image *a d*, similar to the lower extremity *B* of the object *A B*. But by passing through the plano-convex glass *R* in their way, they form that extremity of the image at *b*. In like manner, the rays *E*, which come from the top of the object *A B*, and fall parallel upon the great mirror at *F*, are thence reflected converging to its focus, where they form the lower extremity *K* of the inverted image *I K*, similar to the upper extremity *A* of the object *A B*; and thence passing on to the small mirror *L*, and falling upon it at *h*, they are thence reflected in the converging state *h O*; and going on through the hole *P* of the great mirror, they will meet somewhere about *q*, and form there the upper extremity *a* of the erect image *a d*, similar to the upper extremity *A* of the object *A B*: but, by passing through the convex glass *R* in their way, they meet and cross sooner as at *a*, where that point of the erect image is formed.— The like being understood of all those rays which flow from the intermediate points of the object, between *A* and *B*, and enter the tube *T T*; all the intermediate points of the image between *a* and *b* will be formed: and the rays passing on from the image through the eye-glass *S*, and through a small hole *e* in the end of the lesser tube *t t*, they enter the eye *f*, which sees the image *a d* (by means of the eye-glass) under the large angle *c e d*, and magnified in length, under that angle from *c* to *d*.

In the best reflecting telescopes, the focus of the small mirror is never coincident with the focus *m* of the great one, where the first image *I K* is formed, but a little beyond it (with respect to the eye) as at *n*: the consequence of which is, that the rays of the pencils will not be parallel after reflection from the small mirror,

but converge so as to meet in points about *q e r*; where they would form a larger upright image than *a d*, if the glass *R* was not in their way: and this image might be viewed by means of a single eye-glass properly placed between the image and the eye: but then the field of view would be less, and consequently not so pleasant; for which reason, the glass *R* is still retained, to enlarge the scope or area of the field.

To find the magnifying power of this telescope, multiply the focal distance of the great mirror by the distance of the small mirror from the image next the eye, and multiply the focal distance of the small mirror by the focal distance of the eye-glass: then, divide the product of the former multiplication by the product of the latter, and the quotient will express the magnifying power.

I shall here set down the dimensions of one of *Mr. Short's* reflecting telescopes, as described in *Dr. Smith's* Optics.

The focal distance of the great mirror 9.6 inches, its breadth 2.3; the focal distance of the small mirror 1.5, its breadth 0.6: the breadth of the hole in the great mirror 0.5; the distance between the small mirror and the next eye-glass 14.2; the distance between the two eye-glasses 2.4; the focal distance of the eye-glass next the metal 3.8: and the focal distance of the eye-glass next the eye 1.1.*

One great advantage of the reflecting telescope is, that it will admit of an eye-glass of a much shorter focal distance than a refracting telescope will; and, consequently, it will magnify so much the more: for the rays

Note 69. One of the largest telescopes yet constructed, was contrived by Dr. Herschel under the patronage of his late Majesty This gigantic intrument is about forty feet in length, and the great metallic reflector weighs more than 2000 pounds. A very powerful instrument, constructed on the same principles, and by the same ingenious astronomer is now the property of the London Institution, though unfortunately the want of an observatory has hitherto prevented its useful application.

LECT. VII. are not coloured by reflection from a concave mirror, if it be ground to a true figure, as they are by passing through a convex-glass, let it be ground ever so true.

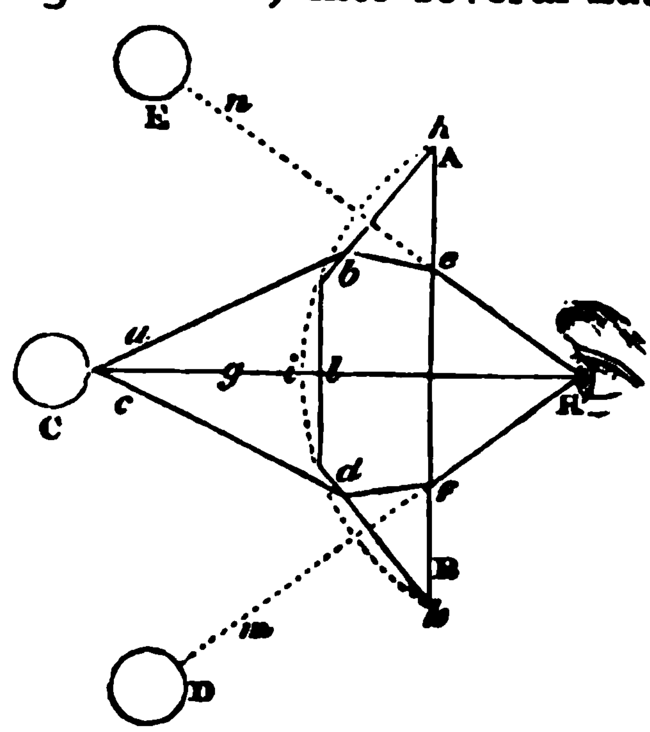
The adjusting screw on the outside of the great tube fits this telescope to all sorts of eyes, by bringing the small mirror either nearer to the eye, or removing it farther: by which means, the rays are made to diverge a little for short-sighted eyes, or to converge for those of a long sight.

The nearer an object is to the telescope, the more its pencils of rays will diverge before they fall upon the great mirror, and therefore they will be the longer of meeting in points after reflection; so that the first image *I K* will be formed at a greater distance from the large mirror, when the object is near the telescope, than when it is very remote. But as this image must be formed farther from the small mirror than its principal focus, *n*, this mirror must be always set at a greater distance from the large one, in viewing near objects, than in viewing remote ones. And this is done by turning the screw on the outside of the tube, until the small mirror be so adjusted, that the object (or rather its image) appears perfect.

In looking through any telescope towards an object, we never see the object itself, but only that image of it which is formed next the eye in the telescope. For, if a man holds his finger or a stick between his bare eye and an object, it will hide part (if not the whole) of the object from his view. But if he ties a stick across the mouth of a telescope, before the object-glass, it will hide no part of the imaginary object he saw through the telescope before, unless it covers the whole mouth of the tube: for all the effect will be, to make the object appear dimmer, because it intercepts part of the rays. Whereas, if he puts only a piece of wire across the inside of the tube, between the eye-glass and his eye, it will hide part of the object which he thinks he sees:

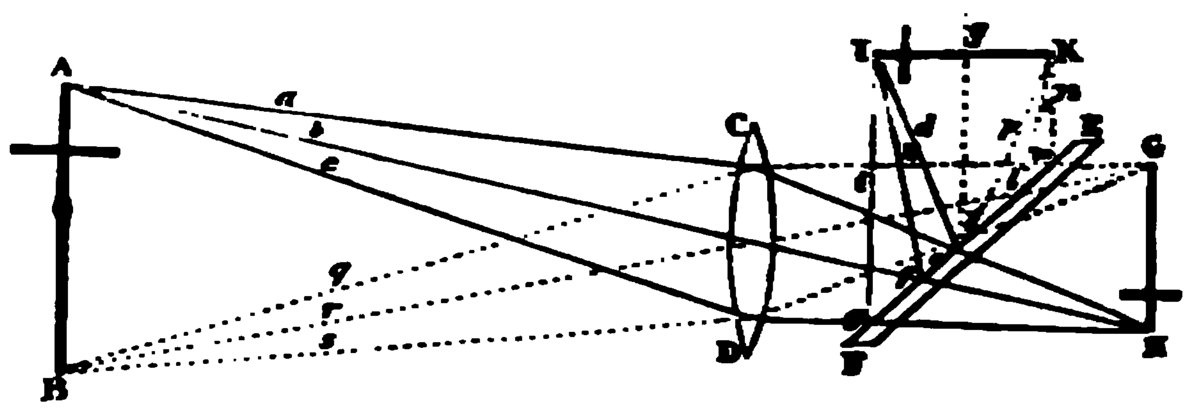
which proves that he sees not the real object, but its image. This is also confirmed by means of the small mirror *L* in the reflecting telescope, which is made of opaque metal, and stands directly between the eye and the object towards which the telescope is turned; and will hide the whole object from the eye at *e*, if the two glasses *R* and *S* are taken out of the tube. LECT. VII.

The multiplying glass. The multiplying glass is made by grinding down the round side *h i k* of a convex glass *A B*, into several flat surfaces, as *h b*, *b l d*, *d k*. An object *C* will not appear magnified, when seen through this glass, by the eye at *H*; but it will appear multiplied into as many different objects as the glass contains plane surfaces. For, since rays will flow from the object *C* to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye, in the direction of the rays which enter it through each surface. Thus, a ray *g i H*, falling perpendicularly on the middle surface, will go through the glass to the eye without suffering any refraction; and will therefore shew the object in its true place at *C*: whilst a ray *a b* flowing from the same object, and falling obliquely on the plane surface *b h*, will be refracted in the direction *b e*, by passing through the glass; and upon leaving it, will go on to the eye in the direction *e H*; which will cause the same object *C* to appear also at *E*, in the direction of the ray *H e*, produced in the right line *H e n*. And the ray *c d*, flowing from the object *C*, and falling obliquely on the plane surface *d k*, will be refracted (by passing through the glass and leaving it at *f*) to the eye at *H*; which will cause the



LECT. VII. same object to appear at *D*, in the direction *H f n*.—If the glass be turned round the line *g l H*, as an axis the object *C* will keep its place, because the surface *b l d* is not removed; but all the other objects will seem to go round *C*, because the oblique planes, on which the rays *a b*, *c d* fall, will go round by the turning of the glass.

The camera obscura. The *camera obscura* is made by a convex glass *C D*,



placed in a hole of a window-shutter. Then, if the room be darkened so that no light can enter but what comes through the glass, the pictures of all the objects (as fields, trees, buildings, men, cattle, &c.) on the outside, will be shewn in an inverted order, on a white paper placed at *G H* in the focus of the glass; and will afford a most beautiful and and perfect piece of perspective or landscape of whatever is before the glass; especially if the sun shines upon the objects.

If the convex glass *C D* be placed in a tube in the side of a square box, within which is the plane mirror *E F*, reclining backwards in an angle of 45 degrees from the perpendicular *k q*, the pencils of rays flowing from the outward objects, and passing through the convex glass to the plane mirror, will be reflected upwards from it, and meet in points, as *I* and *K* (at the same distance that they would have met at *H* and *G*, if the mirror had not been in the way) and will form the aforesaid images on an oiled paper stretched horizontally in the direction *I K*; on which paper, the outlines of the images may be easily drawn with a black-lead pencil,

and then copied on a clean sheet, and coloured by art as the objects themselves are by nature.—In this machine, it is usual to place a plane glass, unpolished, in the horizontal situation *I K*, which glass receives the images of the outward objects; and their outlines may be traced upon it by a black-lead pencil.

N. B. The tube in which the convex glass *C D* is fixed, must be made to draw out, or push in, so as to adjust the distance of that glass from the plane mirror, in proportion to the distance of the outward objects; which the operator does, until he sees their images distinctly painted on the horizontal glass at *I K*.

The forming a horizontal image, as *I K*, of an upright object *A B*, depends upon the angles of incidence of the rays upon the plane mirror *E F*, being equal to their angles of reflection from it. For, if a perpendicular be supposed to be drawn to the surface of the plane mirror at *e*, where the ray *A a C e* falls upon it, that ray will be reflected upwards in an equal angle with the other side of the perpendicular, in the line *e d I*. Again, if a perpendicular be drawn to the mirror from the point *f*, where the ray *A b f* falls upon it, that ray will be reflected in an equal angle from the other side of the perpendicular, in the line *f h I*. And if a perpendicular be drawn from the point *g*, where the ray *A c g* falls upon the mirror, that ray will be reflected in an equal angle from the other side of the perpendicular, in the line *g i l*. So that all the rays of the pencil *a b c*, flowing from the upper extremity of the object *A B*, and passing through the convex glass *C D*, to the plane mirror *E F*, will be reflected from the mirror, and meet at *I*, where they will form the extremity *I* of the image *I K*, similar to the extremity *A* of the object *A B*. The like is to be understood of the pencil *q r s*, flowing from the lower extremity of the object *A B*, and meeting at *K* (after reflection from the plane mirror (the rays form the extremity *K* of the image, similar to the extremity *B* of the

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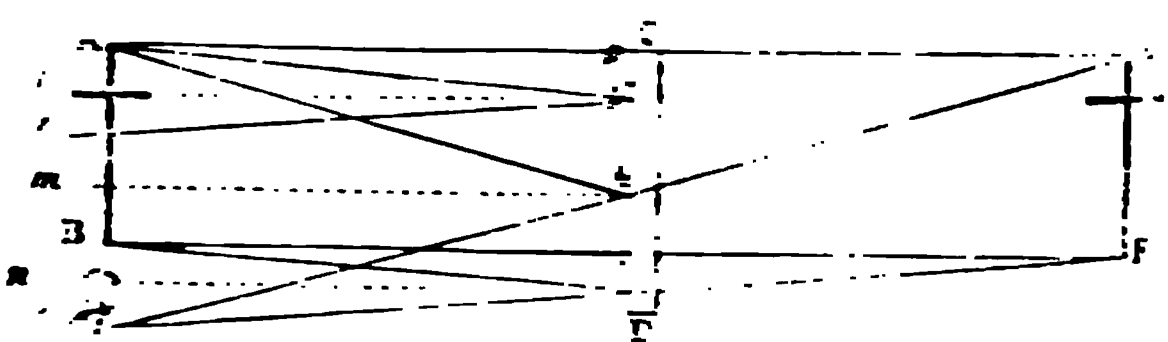
object; and so of all the pencils that flow from the intermediate points of the object to the mirror, through the convex glass.

The opera glass.

If a convex glass, of a short focal distance, be placed near the plane mirror, in the end of a short tube, and a convex glass be placed in a hole in the side of the tube, so that the image may be formed between the last-mentioned convex glass and the plane mirror; the image being viewed through this glass will appear magnified. —In this manner the opera-glasses are constructed; with which a gentleman may look at any lady at a distance in the company, and the lady know nothing of it.

The image of any object that is placed before a plane mirror, appears as big to the eye as the object itself; and is erect, distinct, and seemingly as far behind the mirror, as the object is before it: and that part of the mirror, which reflects the image of the object to the eye (the eye being supposed equally distant from the glass with the object, is just half as long and half as broad as the object itself. Let *A B* be an object placed be-

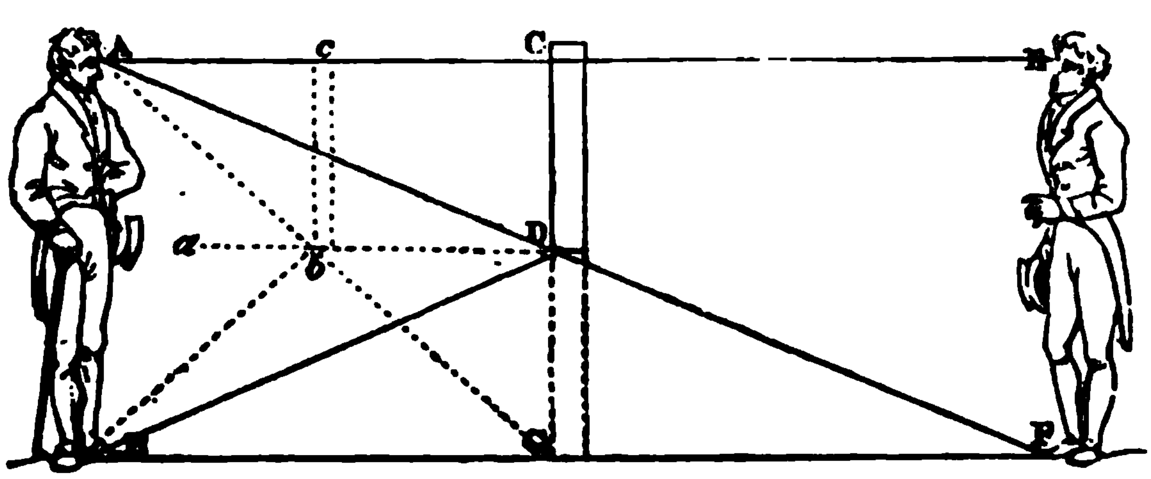


fore the reflecting surface *g h i* of the plane mirror *C D*; and let the eye be at *o*. Let *A h* be a ray of light flowing from the top *A* of the object, and falling upon the mirror at *h*: and *h m* be a perpendicular to the surface of the mirror at *h*: the ray *A h* will be reflected from the mirror at the eye at *o*, making an angle *m h o* equal to the angle *A h m*: then will the top of the image *E* appear to the eye in the direction of the reflected ray *o h* produced to *E*, where the right line *A p E*, from the top of the object, cuts the right line *o h E*, at *E*. Let *B i* be a ray of light proceeding from the foot of the ob-

ject at *B* to the mirror at *i;* and *n i* a perpendicular to the mirror from the point *i*, where the ray *B i* falls upon it: this ray will be reflected in the line *i o*, making an angle *n i o*, equal to the angle *B i n*, with that perpendicular, and entering the eye at *o:* then will the foot *F* of the image appear in the direction of the reflected ray *o i*, produced to *F*, where the right line *B F* cuts the reflected ray produced to *F*. All the other rays that flow from the intermediate points of the object *A B*, and fall upon the mirror between *h* and *i*, will be reflected to the eye at *o;* and all the intermediate points of the image *E F* will appear to the eye in the direction-line of these reflected rays produced. But all the rays that flow from the object, and fall upon the mirror above *h*, will be reflected back above the eye at *o;* and all the rays that flow from the object, and fall upon the mirror below *i*, will be reflected back below the eye at *o:* so that none of the rays that fall above *h*, or below *i*, can be reflected to the eye at *o;* and the distance between *h* and *i* is equal to half the length of the object *A B*.

A man will see his image in a plane looking-glass, that is but half his height.

Hence it appears, that if a man sees his whole image in a plane looking-glass, the part of the glass that reflects his image must be just half as long and half as broad as himself, let him stand at any distance from it whatever; and that his image must appear just as far behind the glass as he is before it. Thus, the man *A B*



viewing himself in the plain mirror *C D*, which is just

LECT VII. half as long as himself, sees his whole image as at $E\ F$, behind the glass, exactly equal to his own size. For, a ray $A\ C$ proceeding from his eye at A, and falling perpendicularly upon the surface of the glass at C, is reflected back to his eye in the same line $C\ A$; and the eye of his image will appear at E, in the same line produced to E, beyond the glass. And a ray $B\ D$, flowing from his foot, and falling obliquely on the glass at D, will be reflected as obliquely on the other side of the perpendicular $a\ b\ D$, in the direction $D\ A$; and the foot of his image will appear at F, in the direction of the reflected ray $A\ D$, produced to F, where it is cut by the right line $B\ G\ F$, drawn parallel to the right line $A\ C\ E$. Just the same as if the glass were taken away, and a real man stood at F, equal in size to the man standing at B: for to his eye at A, the eye of the other man at E would be seen in the direction of the line $A\ C\ E$; and the foot of the man at F would be seen by the eye A, in the direction of the line $A\ D\ F$.

If the glass be brought nearer the man $A\ B$, as suppose to $c\ b$, he will see his image as at $C\ D\ G$: for the reflected ray $C\ A$ (being perpendicular to the glass) will shew the eye of the image as at C; and the incident ray $B\ b$, being reflected in the line $b\ A$, will shew the foot of his image as at G; the angle of reflection $a\ b\ A$ being always equal to the angle of incidence $B\ b\ a$: and so of all the intermediate rays from A to B. Hence, if the the man $A\ B$ advances towards the glass $C\ D$, his image will approach towards it; and if he recedes from the glass, his image will also recede from it.[70]

Note 70. The *Kaleidoscope*, which consists of a combination of plane mirrors may justly be considered as the most amusing of all optic toys; and, indeed, its application to the ornamental parts of our manufactures, gives it a claim of a still higher nature.

One of the earliest forms of the Kaleidoscope, was an instrument proposed by Mr. Bradley in 1717. This merely consisted of two plane

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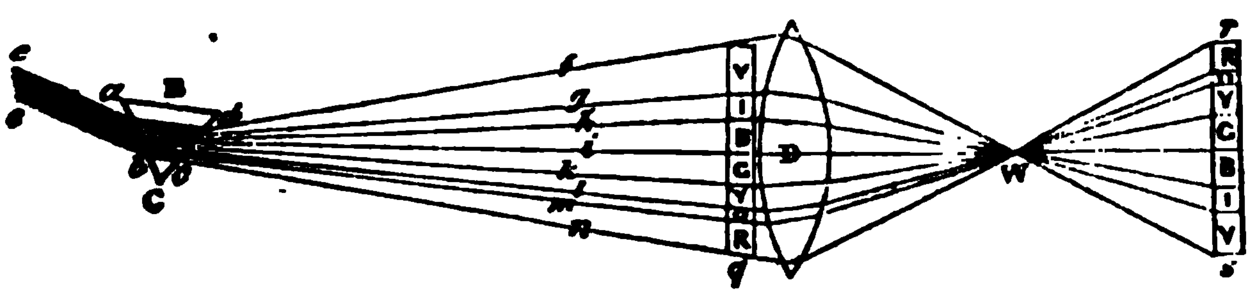
Having already shewn, that the rays of light are refracted when they pass obliquely through different mediums, we come now to prove that some rays are more refrangible than others; and that, as they are differently refracted, they excite in our minds the ideas of different colours. This will account for the colours seen about the edges of the images of those objects which are viewed through some telescopes.

Let the sun shine into a dark room through a small hole as at *e e*, in a window-shutter; and place a triangular



prism *B C* in the beam of rays *A*, in such a manner, that the beam may fall obliquely on one of the sides *a b C* of the prism. The rays will suffer different refractions by passing through the prism, so that instead of going all out of it on the side *d c C*, in one direction, they will go on from it in the different directions represented by the lines *f, g, h, i, k, l, m, n*; and falling on the opposite side of the room, or on white paper placed as at *p q*, to receive them, they will paint upon it a series of most beautiful and lively colours (not to be equalled by art) in this order, viz. those rays which are least refracted by the prism, and will therefore go on between the lines *n* and *m*, will be of a very bright intense red at *n*, degenerating from thence gradually

The *prism.*

The *colours of the light.*

mirrors, jointed together with hinges, and opening like a book. So that the polished plates, being set upon a geometrical drawing, and the observer placed in the front: the lines of the drawing are seen multiplied by repeated reflections. Brief notices of the principle of this invention may also be found in Wood's Optics; and, in a similar Work, by Harris; but it is to Dr. Brewster, that we are indebted for the present improved form of this beautiful instrument.

LECT. VII. into an orange colour, as they are nearer the line *n*: the next will be of a fine orange colour at *m*, and from thence degenerate into a yellow colour towards *l*: at *l* they will be of a fine yellow, which will incline towards a green, more and more, as they are nearer and nearer *k*: at *k* they will be a pure green, but from thence towards *i* they will incline gradually to a blue: at *i* they will be a perfect blue, inclining to an indigo colour from thence towards *h*: at *h* they will be quite the colour of indigo, which will gradually change towards a violet, the nearer they are to *g*: and at *g* they will be of a fine violet colour, which will incline gradually to a red as they come nearer to *f*, where the coloured image ends.

There is not an equal quantity of rays in each of these colours; for, if the oblong image *p q* be divided into 360 equal parts, the red space *R* will take up 45 of these parts; the orange *O*, 27; the yellow *Y*, 48; the green *G*, 60; the blue *B*, 60; the indigo *I*, 40; and the violet *V*, 80: all which spaces are as nearly proportioned in the figure as the small space *p q* would admit of.

If all these colours be blended together again, they will make a pure white; as is proved thus. Take away the paper on which the colours *p q* fell, and place a large convex glass *D* in the rays *f*, *g* *h*, &c which will refract them so, as to make them unite and cross each other at *W*: and if a white paper be placed to receive them, they will excite the idea of a strong lively white. But if the paper be placed farther from the glass, as at *r s*, the different colours will appear again upon it, in an inverted order, occasioned by the rays crossing at *W*.

As white is a composition of all colours. so black is a privation of them all, and therefore, properly no colour.

Let two concentric circles be drawn on a smooth

round board *A B C D E F G*, and the outermost of them divided into 360 equal parts or degrees: then, draw seven right lines, as ⊙ *A*, ⊙ *B*, &c. from the center to the outermost circle; making the lines ⊙ *A* and ⊙ *B* include 80 degrees of that circle; the lines ⊙ *B* and ⊙ *C* 40 degrees; ⊙ *C* and ⊙ *D* 60; ⊙ *D* and ⊙ *E* 60; ⊙ *E* and ⊙ *F* 48; ⊙ *F* and ⊙ *G* 27; ⊙ *G* and ⊙ *A* 45. Then, between these two circles, paint the space *A G* red, inclining to orange near *G*; *G F* orange, inclining to yellow near *F*; *F E* yellow, inclining to green near *E*; *E D* green, inclining to blue near *D*; *D C* blue, inclining to indigo near *C*; *C B* indigo, inclining to violet near *B*; and *B A* violet, inclining to a soft red near *A*. This done, paint all that part of the board black which lies within the inner circle; and putting an axis through the center of the board, let it be turned very swiftly round that axis, so that the rays proceeding from the above colours, may be all blended and mixed together in coming to the eye; and then, the whole coloured part will appear like a white ring, a little greyish; not perfectly white, because no colours prepared by art are perfect.

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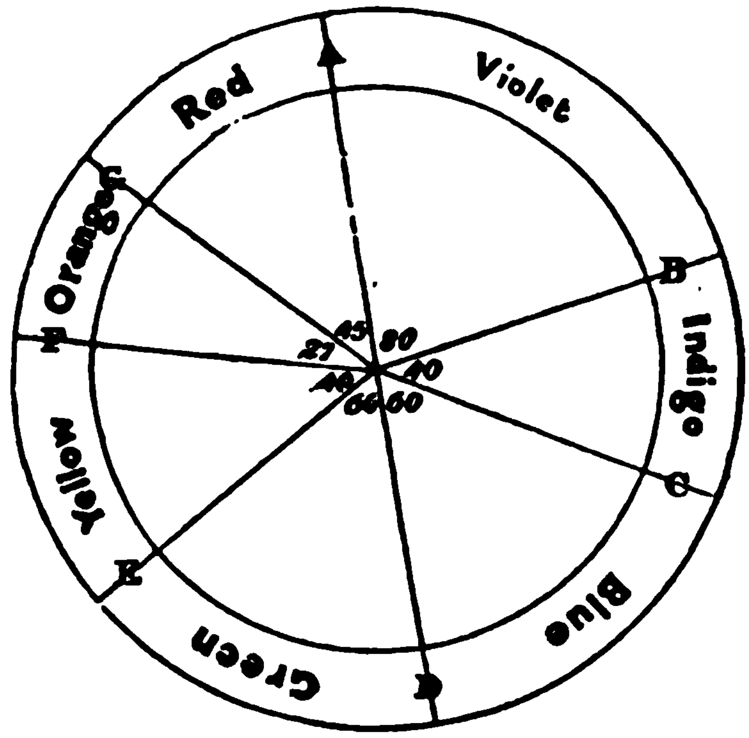

All the prismatic colours blended together, make a white.

Any of these colours, except red and violet, may be made by mixing together the two contiguous prismatic colours. Thus, yellow is made by mixing together a due proportion of orange and green; and green may be made by a mixture of yellow and blue.

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All bodies appear of that colour, whose rays they reflect most; as a body appears red when it reflects most of the red-making rays, and absorbs the rest.

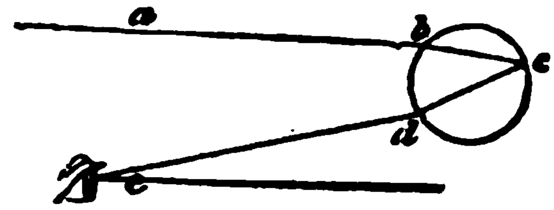
Transparent colours become opaque if put together.

Any two or more colours that are quite transparent by themselves, become opaque when put together. Thus, if water or spirits of wine be tinged red, and put in a phial, every object seen through it will appear red; because it lets only the red rays pass through it, and stops all the rest. If water or spirits be tinged blue, and put in a phial, all objects seen through it will ap pear blue, because it transmits only the blue rays, and stops all the rest. But if these two phials are held close together, so that both of them may be between the eye and object, the object will no more be seen through them than through a plate of metal; for whatever rays are transmitted through the fluid in the phial next the object, are stopped by that in the phial next the eye. In this experiment, the phials ought not to be round, but square; because nothing but the light itself can be seen through a round transparent body, at any distance.

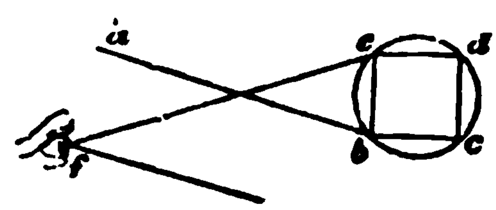
As the rays of light suffer different degrees of refraction by passing obliquely through a prism, or through a convex glass, and are thereby separated into all the seven original or primary colours; so they also suffer different degrees of refraction by passing through drops of falling rain; and then, being reflected towards the eye, from the sides of these drops which are farthest from the eye, and again refracted by passing out of these drops into the air, in which refracted directions they come to the eye; they make all the colours to appear in the form of a fine arch in the heavens, which is called the *rain-bow*.

There are always two rain-bows seen together, the interior of which is formed by the rays *a b*, which falling upon the upper part *b*, of the drop *c d b*, are re-

fracted into the line *b c* as they enter the drop, and are reflected from the back of it at *c*, in the line *c d*, and then, by passing out of the drop into air, they are again refracted at *d;* and from thence they pass on to the eye et *e:* so that to form the interior bow, the rays suffer two refractions, as at *b* and *d;* and one reflection, as at *c*.



The exterior bow is formed by rays which suffer two reflections, and two refractions; which is the occasion of its being less vivid than the interior, and also of its colours being inverted with respect to those of the interior. For, when a ray *a b* falls upon the lower part of the drop *b c d e*, it is refracted into the direction *b c* by entering the drop; and passing on to the back of the drop at *c*, it is thence reflected in the line *c d*, in which direction it is impossible for it to enter the eye at *f:* but by being again reflected from the point *d* of the drop, it goes on in the drop to *e*, where it passes out of the drop into the air, and is there refracted downward to the eye, in the direction *e f*



LECT. VIII. & IX.

LECTURES VIII. AND IX.

THE DESCRIPTION AND USE OF THE GLOBES, AND ARMILLARY SPHERE.

The terrestrial globe.

IF a map of the world be accurately delineated on a spherical ball, the surface thereof will represent the surface of the earth: for the highest hills are so inconsiderable with respect to the bulk of the earth, that they take off no more from its roundness, than grains of sand do from the roundness of a common globe; for the diameter of the earth is 8000 miles in round numbers, and no known hill upon it is three miles in perpendicular height.[71]

Proof of the earth's being globular.

That the earth is spherical, or round like a globe, appears, 1. From its casting a round shadow upon the moon, whatever side be turned towards her when she is eclipsed. 2. From its having been sailed round by several persons. 3. From our seeing the farther, the higher we stand. 4. From our seeing the masts of a ship, whilst the hull is hid by the convexity of the water.[72]

And that it may be peopled on all sides without any one being in danger of falling away from it.

The attractive power of the earth draws all terrestrial bodies towards its center; as is evident from the descent of bodies in lines perpendicular to the earth's surface, at the places whereon they fall; even when they are thrown off from the earth on opposite sides, and consequently, in opposite directions. So that the

Note 71. The principal mountains of the earth have lately been delineated on a terrestrial globe, contrived by an Italian. It will, however, be apparent, from what our Author has stated above, that the proportions could not have been accurately represented.

Note 72. It may be proper to repeat what has been already stated, that the earth is not a perfect sphere, but an oblate spheroid: the poles being depressed, while the equator is expanded.

earth may be compared to a great magnet, rolled in filings of steel, which attracts and keeps them equally fast to its surface on all sides. Hence, as all terrestrial bodies are attracted towards the earth's center, they can be in no danger of falling from any one side of the earth, more than another.[78]

Up and down, what.

The heaven or sky surrounds the whole earth: and when we speak of *up* or *down*, we mean only with regard to ourselves; for no point, either in the heaven or on the surface of the earth, is *above* or *below*, but only with respect to ourselves. And let us be upon what part of the earth we will, we stand with our feet towards its center, and our heads towards the sky: and so we say, it is *up* towards the sky, and *down* towards the center of the earth.

All objects in the heavens appear equally distant.

To an observer placed any where in the indefinite space, where there is nothing to limit his view, all remote objects appear equally distant from him; and seem to be placed in a vast concave sphere, of which his eye is the center. Every astronomer can demonstrate, that the moon is much nearer to us than the sun is; that some of the planets are sometimes nearer to us, and sometimes farther from us, than the sun; that others of them never come so near us as the sun always is; that the remotest planet in our system is beyond comparison nearer to us than any of the fixed stars are; and that it is highly probable some stars are, in a manner, infinitely more distant from us than others. And yet all these celestial objects appear equally distant from us. Therefore, if we imagine a large hollow sphere of glass to have as many bright studs fixed to its inside as there are stars visible in the heavens, and these

The face of the heaven and earth represented in a machine.

Note 78. A reference to this fact will shew that two pendulums or plumb-lines suspended freely on the earth's surface, would not hang parallel to each other, but assume such a direction as would bring them in contact at the center of gravity of the globe.

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studs to be of different magnitudes, and placed at the same angular distance from each other as the stars are, the sphere will be a true representation of the starry heaven, to an eye supposed to be in its center, and viewing it all around. And if a small globe, with a map of the earth upon it, be placed on an axis in the center of this starry sphere, and the sphere be made to turn round on this axis, it will represent the apparent motion of the heaven round the earth.

The equinoctial. If a great circle be so drawn upon this sphere as to divide it into two equal parts, or hemispheres, and the plane of the circle be perpendicular to the axis of the sphere, this circle will represent the *equinoctial*, which divides the heavens into two equal parts, called the *northern* and the *southern hemispheres;* and every point of that circle will be equally distant from the *poles*, or ends of the axis in the sphere. That pole which is in the middle of the northern hemisphere, will be called the *north pole of the sphere*, and that which is in the middle of the southern hemisphere, the *south pole*.

The poles.

The ecliptic. If another great circle by drawn upon the sphere, in in such a manner as to cut the equinoctial at an angle of $23\frac{1}{2}$ degrees in two opposite points, it will represent the *ecliptic*, or circle of the sun's apparent annual motion; one half of which is on the north side of the equinoctial, and the other half on the south.

The sun. If a large stud be made to move eastward in this ecliptic in such a manner as to go quite round it, in the time that the sphere is turned round westward 366 times upon its axis; this stud will represent the *sun*, changing his place every day a 365th part of the ecliptic; and going round westward, the same way as the stars do; but with a motion so much slower than the motion of the stars, that they will make 366 revolutions about the axis of the sphere, in the time that the

sun makes only 365. During one half of these revolutions, the sun will be on the north side of the equinoctial; during the other half, on the south; and at the end of each half, in the eqinoctional.

The earth.

If we suppose the terrestrial globe in this machine to be about one inch in diameter, and the diameter of the starry sphere to be about five or six feet, a small insect on the globe would see only a very little portion of its surface; but it would see one half of the starry sphere, the convexity of the globe hiding the other half from its view. If the sphere be turned westward round the globe, and the insect could judge of the appearances which arise from that motion, it would see some stars rising to its view in the eastern side of the sphere, whist others were setting on the western: but as all the stars are fixed to the sphere, the same stars would always rise in the same points of view on the east side, and set in the same points of view on the west side. With the sun it would be otherwise, because the sun is not fixed to any point of the sphere, but moves slowly along an oblique circle in it. And if the insect should look towards the south, and call that point of the globe, where the equinoctial in the sphere seems to cut it on the left side, the *east point:* and where it cuts the globe on the right side, the *west point:* the little animal would see the sun rise north of the east, and set north of the west, for 182 revolutions; after which, for as many more, the sun would rise south of the east, and set south of the west. And in the whole 365 revolutions, the sun would rise only twice in the east point, and set twice in the west. All these appearances would be the same, if the starry sphere stood still (the sun only moving in the ecliptic) and the earthly globe were turned round the axis of the sphere eastward. For, as the insect would be carried round with the globe, he would be quite insensible of its motion; and the sun and stars would appear to move westward.

The apparent motion of the heavens.

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We are but very small beings when compared with our earthly globe, and *the globe itself* is but a dimensionless point compared with the magnitude of the starry heavens. Whether the earth be at rest and the heaven turns round it, or the heaven be at rest, and the earth turns round, the appearance to us will be exactly the same. And because the heaven is so immensely large, in comparison of the earth, we see one half of the heaven as well from the earth's surface, as we could do from its center, if the limits of our view were not intercepted by hills.

The opera glass.

Circles of the sphere.

We may imagine as many circles described upon the earth as we please; and we may imagine the plane of any circle described upon the earth to be continued, until it marks a circle in the concave sphere of the heaven.

The horizon.

The *horizon* is either *sensible* or *rational*. The *sensible* horizon is that circle, which a man standing upon a large place, observes to terminate his view all around where the heaven and earth seem to meet. The plane of our sensible horizon continued to the heaven, divides it into two hemispheres; one visible to us, the the other hid by the convexity of the earth.

The plane of the *rational horizon,* is supposed parallel to the plane of the sensible; to pass through the center of the earth, and to be continued through the heavens. And although the plane of the sensible horizon touches the earth in the place of the observer, yet *this* plane, and *that* of the rational horizon, will seem to coincide in the heaven, because the whole earth is but a point compared to the sphere of the heaven.

The earth being a spherical body, the horizon or limit of our view must change as we change our place.

Poles.

The *poles of the earth* are those two points on its surface in which its axis terminates. The one is called the *north pole,* and the other the *south pole.*

The *poles of the heaven,* are those two points in which the earth's axis produced terminates in the heaven: so

that the *north pole* of the heaven is directly over the north pole of the earth; and the *south pole* of the heaven is directly over the south pole of the earth. LECT. VIII. & IX.

Equator. The *equator* is a great circle upon the earth, every part of which is equally distant from either of the two poles. It divides the earth into two equal parts, called the *northern* and *southern hemispheres*. If we suppose the plane of this circle to be extended to the heaven, it will mark the *equinoctial* therein, and will divide the heaven into two equal parts, called the *northern* and *southern* hemispheres of the heaven.

Meridian. The *meridian* of any place is a great circle passing through that place and the poles of the earth. We may imagine as many such meridians as we please, because any place that is ever so little to the east or west of any other place, has a different meridian from that place; for no one circle can pass through any two such places and the poles of the earth.

The *meridian* of any place is divided by the poles into two semicircles: that which passes through the place is called the *geographical*, or *upper meridian*; and that which passes through the opposite place, the *lower meridian*.

Noon and mid night. When the rotation of the earth brings the plane of the geographical meridian to the sun, it is *noon* or *midday*, to that place; and when our lower meridian comes to the sun, it is *midnight*.

All places lying under the same geographical meridian, have their noon at the same time, and consequently all the other hours. All those places are said to have the same *longitude*, because no one of them lies either eastward or westward from any of the rest.

Hour circles. If we imagine 24 semicircles, one of which is the geographical meridian of a given place, to meet at the poles and to divide the equator into 24 equal parts: each of these meridians will come round to the sun in 24 hours by the earth's equable motion round its axis in that time. And, as the equator contains 360 degrees, there

LECT. VIII. & IX. will be 15 degrees contained between any two of these meridians which are nearest to one another; for 24 times 15 is 360. And as the earth's motion is eastward, the sun's apparent motion will be westward, at the rate of 15 degrees each hour. Therefore,

Longitude. They whose geographical meridian is fifteen degrees eastward from us, have noon, and every other hour, an hour sooner than we have. They whose meridian is fifteen degrees westward from us, have noon, and every other hour, an hour later than we have; and so on in proportion, reckoning one hour for every fifteen degrees.

As the earth turns round its axis once in 24 hours, and shews itself all round to the sun in that time; so it goes round the sun once a year, in a great circle call-

Ecliptic. ed the *ecliptic*, which crosses the equinoctial in two opposite points, making an angle of 32½ degrees with the equinoctial on each side. So that one half of the ecliptic is in the northern hemisphere, and the other in the southern. It contains 360 equal parts, called degrees, (as all other circles do, whether great or small) and as the earth goes once round in every year, the sun will appear to do the same, changing his place almost a degree, at a mean rate, every 24 hours. So that whatever place or degree of the ecliptic, the earth is in at any time, the sun will then appear in the opposite.

And as one half of the ecliptic is on the north side of the equinoctial, and the other half on the south; the sun as seen from the earth, will be half a year on the south side of the equinoctial, and half a year on the north; and twice a year in the equinoctial itself.

Signs and Degrees. The ecliptic is divided by astronomers into 12 equal parts, called *signs*, each sign into 30 *degrees*, and each degree into 60 *minutes;* but in using the globes, we seldom want the sun's place nearer than half a degree of the truth.

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The names and characters of the 12 signs are as follow: beginning at that point of the ecliptic where it crosses the equinoctial to the northward, and reckoning eastward round to the same point again. And the days of the months on which the sun now enters the signs, are set down below them.

Aries,	*Taurus,*	*Gemini,*	*Cancer,*
♈	♉	♊	♋
March	April	May	June
20	20	21	21
Leo,	*Virgo,*	*Libra,*	*Scorpio,*
♌	♍	♎	♏
July	August	September	October
23	23	23	23
Sagittarius,	*Capricorn,*	*Aquarius,*	*Pisces*
♐	♑	♒	♓
November	December	January	February.
22	21	20	18

By remembering on what day the sun enters any particular sign, we may easily find his place any day afterward, whilst he is in that sign, by reckoning a degree for each day; which will occasion no error of consequence in using the globes.

When the sun is at the beginning of *Aries*, he is in the equinoctial; and from that time he declines northward every day, until he comes to the beginning of *Cancer*, which is 23½ degrees from the equinoctial: from thence he recedes southward every day, for half a year; in the middle of which half, he crosses the equinoctial at the beginning of *Libra;* and at the end of that half year, he is at his greatest south declination, in the beginning of *Capricorn*, which is also 23½ degrees from the equinoctial. Then, he returns northward from

LECT. VIII.& IX. *Capricorn* every day, for half a year; in the middle of which half, he crosses the equinoctial at the beginning of *Aries;* and at the end of it he arrives at *Cancer.*

The sun's motion in the ecliptic is not perfectly equable, for he continues eight days longer in the northern half of the ecliptic, than in the southern: so that the summer half year, in the northern hemisphere, is eight days longer than the winter half year; and the contrary in the southern hemisphere.[74]

Tropics. The *tropics* are lesser circles in the heaven, parallel to the equinoctial; one on each side of it, touching the ecliptic in the points of its greatest declination; so that each tropic is 23½ degrees from the equinoctial, one on the north side of it, and the other on the south. The northern tropic touches the ecliptic at the beginning of *Cancer*, the southern at the beginning of *Capricorn;* for which reason the former is called the *tropic of Cancer,* and the latter the *tropic of Capricorn.*

Polar circles. The *polar circles* in the heaven, are each 23½ degrees from the poles, all around. That which goes round the north pole, is called the *arctic circle,* from αρκτος, which signifies a *bear;* there being a collection or groupe of stars near the north pole, which goes by that name The south polar circle, is called the *antarctic circle,* from its being opposite to the arctic.

The ecliptic, tropics, and polar circles, are drawn upon the terrestrial globe, as well as upon the celestial. But the ecliptic, being a great circle fixed in the heavens, cannot properly be said to belong to the terrestrial globe; and is laid down upon it only for the convenience of solving some problems. So that, if this circle on the terrestrial globe was properly divided into the months and days of the year, it would not only suit the

Note 74. The term *tropic* is derived from a Greek word, which signifies *to turn*, as the sun recedes from these circles immediately after the longest day in the summer, and the shortest in winter.

globe better, but would also make the problems thereon much easier.

In order to form a true idea of the earth's motion round its axis every 24 hours, which is the cause of day and night; and of its motion in the ecliptic round the sun every year, which is the cause of the different lengths of days and nights, and of the vicissitude of seasons; take the following method, which will be both easy and pleasant.

An idea of the seasons.

Let a small terrestrial globe, of about three inches diameter, be suspended by a long thread of twisted silk, fixed to its north pole: then having placed a lighted candle on a table, to represent the sun, in the center of a hoop of a large cask, which may represent the ecliptic, the hoop making an angle of 23½ degrees with the plane of the table; hang the globe within the hoop near to it; and if the table be level, the equator of the globe will be parallel to the table, and the plane of the hoop will cut the equator at an angle of 23½ degrees; so that one half of the equator will be above the hoop, and the other half below it: and the candle will enlighten one half of the globe, as the sun enlightens one half of the earth, whilst the other half is in the dark.

Things being thus prepared, twist the thread towards the left hand, that it may turn the globe the same way by untwisting; that is, from west, by south, to east. As the globe turns round its axis or thread, the different places of its surface will go regularly through the light and dark; and have, as it were, an alternate return of day and night in each rotation. As the globe continues to turn round, and to shew itself all around to the candle, carry it slowly round the hoop by the thread, from west, by south, to east; which is the way that the earth moves round the sun, once a year, in the ecliptic: and you will see, that whilst the globe continues in the lower part of the hoop, the candle (being then north of the equator) will constantly shine round

LECT. VIII. & IX. the north pole; and all the northern places which go through any part of the dark, will go through a less portion of it than they do of the light; and the more so, the farther they are from the equator: consequently, their days are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the highest and lowest points, the candle will be directly over the equator, and will enlighten the globe just from pole to pole; and then every place on the globe will go through equal portions of light and darkness, as it runs round its axis; and consequently, the day and night will be of equal length at all places upon it. As the globe advances thenceforward, towards the highest part of the hoop, the candle will be on the south side of the equator, shining farther and farther round the south pole, as the globe rise higher and higher in the hoop; leaving the north pole as much in darkness, as the south pole is then in the light, and making long days and short nights on the south side of the equator, and the contrary on the north side, whilst the globe continues in the northern or higher side of the hoop: and when it comes to the highest point, the days will be at the longest, and the nights at the shortest, in the southern hemisphere; and the reverse in the northern. As the globe advances and descends in the hoop, the light will gradually recede from the south pole, and approach towards the north pole, which will cause the northern days to lengthen, and the southern days to shorten in the same proportion. When the globe comes to the middle point, between the highest and lowest points of the hoop, the candle will be over the equator, enlightening the globe just frôm pole to pole, when every place of the earth (except the poles) will go through equal portions of light and darkness; and consequently, the day and night will be then equal, all over the globe.

And thus, at a very small expense, one may have a

delightful and demonstrative view of the cause of days and nights, with their gradual increase and decrease in length, through the whole year, together with the vicissitudes of spring, summer, autumn, and winter, in each annual course of the earth round the sun.[75] LECT. VIII & IX.

If the hoop be divided into 12 equal parts, and the signs be marked in order upon it, beginning with *Cancer* at the highest point of the hoop, and reckoning eastward (or contrary to the apparent motion of the sun) you will see how the sun appears to change his place every day in the ecliptic, as the globe advances eastward along the hoop, and turns round its own axis: and that when the earth is in a low sign, as at *Capricorn*, the sun must appear in a high sign, as at *Cancer*, opposite to the earth's real place: and that whilst the earth is in the southern half of the ecliptic, the sun appears in the northern half, and *vice versa:* that the farther any place is from the equator, between it and the polar circle, the greater is the difference between the longest and shortest day at that place, and that the poles have but one day and one night in the whole year.

These things premised, we shall proceed to the description and use of the terrestrial globe, and explain the geographical terms as they occur in the problems.

The *terrestrial globe* described.

This globe has the boundaries of land and water laid down upon it, the countries and kingdoms divided by dots, and coloured to distinguish them, the islands properly situated, the rivers and principal towns inserted, as they have been ascertained upon the earth by measurement and observation.

The equator, ecliptic, tropics, polar circles, and

Note 75. Mr. Christie has contrived an improved apparatus, operating on nearly similar principles, and it is but justice to the above ingenious mathematical Professor to add, that his *tellurian* appears admirably adapted for the purpose of explaining most of the problems described by our Author.

LECT. VIII.&IX. meridians, are laid down upon the globe in the manner already described. The ecliptic is divided into 12 signs, and each sign into 30 degrees, which are generally subdivided into halves, and into quarters if the globe is large. Each tropic is 23½ degrees, from the equator, and each polar circle 23½ degrees from its respective pole. Circles are drawn parallel to the equator, at every ten degrees distance from it on each side of the poles: these circles are called *parallels of latitude*. On large globes there are circles drawn perpendicularly through every tenth degree of the equator, intersecting each other at the poles: but on globes of or under a foot diameter, they are only drawn through every fifteenth degree of the equator; these circles are generally called *meridians*, sometimes *circles of longitude*, and at other times *hour-circles*.

The globe is hung in a brass ring, called the *brazen meridian;* and turns upon a wire in each pole sunk half its thickness into one side of the meridian ring; by which means, *that* side of the ring divides the globe into two equal parts, called the *eastern* and *western hemispheres;* as the equator divides it into two equal parts, called the *northern* and *southern hemispheres*. This ring is divided into 360 equal parts or degrees, on the side wherein the axis of the globe turns. One half of these degrees are numbered, and reckoned, from the equator to the poles, where they end at 90: their use is to shew the latitudes of places. The degrees on the other half of the meridian ring, are numbered from the poles to the equator, where they end at 90: their use is to shew how to elevate either the north or south pole above the horizon, according to the latitude of any given place, as it is north or south of the equator.

The brazen meridian is let into two notches made in a broad flat ring, called the *wooden horizon,* the upper surface of which divides the globe into two equal parts, called the *upper* and *lower hemispheres*. One notch is

in the north point of the horizon, and the other in the south. On this horizon are several concentric circles, which contain the months and days of the year, the signs and degrees answering to the sun's place for each month and day, and the 32 points of the compass.---The graduated side of the brass meridian lies towards the east side of the horizon, and should be generally kept towards the person who works problems by the globes.

There is a small *horary circle*, so fixed to the north part of the brazen meridian, that the wire in the north pole of the globe is in the center of that circle; and on the wire is an *index*, which goes over all the 24 hours of the circle, as the globe is turned round its axis. Sometimes there are two horary circles, one between each pole of the globe and the brazen meridian; which is the contrivance of the late ingenious *Mr. Joseph Harris*, master of the assay-office in the Tower of London; and makes it very convenient for putting the poles of the globe through the horizon, and for elevating the pole to small latitudes and declinations of the sun; which cannot be done where there is only one horary circle fixed to the outer edge of the brazen meridian.

There is a thin slip of brass, called the *quadrant of altitude*, which is divided into 90 equal parts or degrees, answering exactly to so many degrees of the equator. It is occasionally fixed to the uppermost point of the brazen meridian by a nut and screw. The divisions end at the nut, and the quadrant is turned round upon it.

As the globe has been seen by most people, and upon the figure of which, in a plate, neither the circles nor countries can be properly expressed, we judge it would signify very little to refer to a figure of it; and shall therefore only give some directions how to choose a globe, and then describe its use.

Directions for choosing of globe.

1. See that the papers be well and neatly pasted on the globes, which you may know, if the lines and circles

thereon meet exactly, and continue all the way even and whole; the circles not breaking into several arches, nor the papers either coming short, or lapping over one another.

2. See that the colours be transparent, and not laid too thick upon the globe to hide the names of places.

3. See that the globe hang evenly between the brazen meridian and the wooden horizon; not inclining either to one side or to the other.

4. See that the globe be as close to the horizon and meridian as it conveniently may; otherwise, you will be too much puzzled to find against what part of the globe any degree of the meridian or horizon is.

5. See that the equinoctial line be even with the horizon all around, when the north or south pole is elevated 90 degrees above the horizon.

6. See that the equinoctial line cuts the horizon in the east and west points, in all elevations of the pole from 0 to 90 degrees.

7. See that the degree of the brazen meridian marked with 0, be exactly over the equinoctial line of the globe.

8. See that there be exactly half of the brazen meridian above the horizon; which you may know, if you bring any of the decimal divisions on the meridian to the north point of the horizon, and find their complement to 90 in the south point.

9. See that when the quadrant of altitude is placed as far from the equator on the brazen meridian, as the pole is elevated above the horizon, the beginning of the degrees of the quadrant reaches just to the plane surface of the horizon.

10. See that whilst the index by the hour circle (by the motion of the globe) passes from one hour to another, 15 degrees of the equator pass under the graduated edge of the brazen meridian.

11. See that the wooden horizon be made substantial and strong: it being generally observed, that in most

globes, the horizon is the first part that fails, on account of its having been made too slight. LECT. VIII. & IX.

In using the globes, keep the east side of the horizon towards you (unless your problem requires the turning of it) which side you may know by the word East upon the horizon; for then you have the graduated side of the meridian towards you, the quadrant of altitude before you, and the globe divided exactly into two equal parts, by the graduated side of the meridian. Directions for using them.

In working some problems, it will be necessary to turn the whole globe and horizon about, that you may look on the west side thereof; which turning will be apt to jog the ball so, as to shift away that degree of the globe which was before set to the horizon or meridian: to avoid which inconvenience, you may thrust in the feather-end of a quill between the ball of the globe and the brazen meridian; which, without hurting the ball, will keep it from turning in the meridian, whilst you turn the west side of the horizon towards you.

PROBLEM I.

To find the latitude[76] and longitude[77] of any given place upon the globe.

Turn the globe on its axis, until the given place comes exactly under that graduated side of the brazen

Note 76. The latitude of a place is its distance from the equator, and is north or south, as the place is north or south of the equator. Those who live at the equator have no latitude, because it is there that the latitude begins.—*Note by the Author.*

Note 77. The longitude of a place is the number of degrees (reckoned upon the equator) that the meridian of the said place is distant from the meridian of any other place from which we reckon, either eastward or westward, for 180 degrees, or half round the globe. The English reckon the longitude from the meridian of London, and the French now reckon it from the meridian of Paris. The meridian of that place, from which the longitude is reckoned, is called the *first meridian*. The places upon this meridian have no longitude, because it is there that the longitude begins.—*Ibid.*

LECT. VIII. & IX. meridian, on which the degrees are numbered from the equator; and observe what degree of the meridian the place then lies under; which is its latitude, north or south, as the place is north or south of the equator.

The globe remaining in this position, the degree of the equator, which is under the brazen meridian, is the longitude of the place (from the meridian of London on the English globes) which is east or west, as the place lies on the east or west side of the first meridian of the globe.—All the *Atlantic Ocean* and *America*, is on the west side of the meridian of *London*; and the greatest part of *Europe* and of *Africa*, together with all *Asia*, is on the east side of the meridian of *London*, which is reckoned the *first meridian* of the globe by the *English* geographers and astronomers.

PROBLEM II.

The longitude and latitude of a place being given, to find that place on the globe.

Look for the given longitude in the equator (counting it eastward or westward from the first meridian, as it is mentioned to be east or west); and bring the point of longitude in the equator to the brazen meridian, on that side which is above the south point of the horizon; then, count from the equator, on the brazen meridian, to the degree of the given latitude, towards the north or south pole, according as the latitude is north or south; and under that degree of latitude on the meridian, you will have the place required.

PROBLEM III.

To find the difference of longitude, or difference of latitude, between any two given places.

Bring each of these places to the brazen meridian, and see what its latitude is: the lesser latitude subtract-

from the greater, if both places are on the same side the equator, or both latitudes added together, if they on different sides of it, is the difference of latitude uired. And the number of degrees contained be-een these places, reckoned on the equator, when they brought separately under the brazen meridian, is ir difference of longitude, if it be less than 180: but nore, let it be subtracted from 360, and the remainder he difference of longitude required. Or,

Having brought one of the places to the brazen meri-n, and set the hour index to XII, turn the globe il the other place comes to the brazen meridian, and number of hours and parts of an hour, passed over the index, will give the longitude in time; which may easily reduced to degrees, by allowing 15 degrees every hour, and one degree for every four minutes.

V. *B.* When we speak of bringing any place to the zen meridian, it is the graduated side of the meri-n that is meant.

PROBLEM IV.

y place being given, to find all those places that have the same longitude or latitude with it.

Bring the given place to the brazen meridian, then those places which lie under that side of the meri-n, from pole to pole, have the same longitude with given place. Turn the globe round its axis, and all se places which pass under the same degree of the ridian that the given place does, have the same lati-le with that place.

Since all latitudes are reckoned from the equator, l all longitudes are reckoned from the first meridian, s evident, that the point of the equator which is cut the first meridian, has neither latitude nor longitude. The greatest latitude is 90 degrees, because no place more than 90 degrees from the equator. And the

LECT. VIII. & IX. greatest longitude is 180 degrees, because no place is more than 180 degrees from the first meridian.

PROBLEM V.

To find the antœci,[78] periœci,[79] *and* antipodes,[80] *of any given place.*

Bring the given place to the brazen meridian, and having found its latitude, keep the globe in that situation, and count the same number of degrees of latitude from the equator towards the contrary pole, and where the reckoning ends, you have the *antœci* of the given place upon the globe. Those who live at the equator have no *antœci*.

Note 78. The *antœci* are those people who live on the same meridian, and in equal latitudes, on different sides of the equator. Being on the same meridian, they have the same hours; that is, when it is noon to the one, it is also noon to the other: and when it is midnight to the one, it is also midnight to the other, &c. Being on different sides of the equator, they have different or opposite seasons at the same time; the length of any day to the one is equal to the length of the night of that day to the other; and they have equal elevations of the different poles.—*Note by the Author.*

Note 79. The *periœci* are those people who live on the same parallel of latitude, but on opposite meridians: so that though their latitude be the same, their longitude differs 180 degrees. By being in the same latitude, they have equal elevations of the same pole (for the elevation of the pole is always equal to the latitude of the place) the same length of days or nights, and the same seasons. But being on opposite meridians, when it is noon to the one, it is midnight to the other.—*Ibid.*

Note 80. The *antipodes* are those who live diametrically opposite to one another upon the globe, standing with feet towards feet, on opposite meridians and parallels. Being on opposite sides of the equator, they have opposite seasons, winter to one, when it is summer to the other; being equally distant from the equator, they have the contrary poles equally elevated above the horizon; being on opposite meridians, when it is noon to the one, it must be midnight to the other; and as the sun recedes from the one when he approaches to the other, the length of the day to the one must be equal to the length of the night at the same time to the other.—*Ibid.*

The globe remaining in the same position, set the hour index to the upper XII on the horary circle, and turn the globe until the index comes to the lower XII; then, the place which lies under the meridian, in the same latitude with the given place, is the *periœci* required. Those who live at the poles have no *periœci*.

As the globe now stands (with the index at the lower XII) the *antipodes* of the given place will be under the same point of the brazen meridian where its *antœci* stood before. Every place upon the globe has its *antipodes*.

PROBLEM VI

To find the distance between any two places on the globe.

Lay the graduated edge of the quadrant of altitude over both the places, and count the number of degrees intercepted between them on the quadrant; then multiply these degrees by 60, and the product will give the distance in geographical miles: but to find the distance in English miles, multiply the degrees by 69¼, and the product will be the number of miles required. Or take the distance betwixt any two places with a pair of compasses, and apply that extent to the equator; the number of degrees, intercepted between the points of the compasses, is the distance in degrees of a great circle;[81] which may be reduced either to geographical miles, or to English miles, as above.

Note 81. Any circle that divides the globe into two equal parts, is called a *great circle*, as the equator or meridian. Any circle that divides the globe into two unequal parts (which every parallel of latitude does) is called a *lesser circle*. Now as every circle, whether great or small, contains 360 degrees, and a degree upon the equator or meridian contains 60 geographical miles, it is evident that a degree of longitude upon the equator is longer than a degree of longitude upon any parallel of latitude, and must therefore contain a greater number of miles. So that, although all the degrees of latitude are equally long upon an artificial globe (though not precisely so upon the earth itself) yet the degrees of longitude decrease in length, as the latitude increases, but not in the same proportion. The following table shews

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PROBLEM VII.

A place on the globe being given, and its distance from any other place, to find all the other places upon the globe which are at the same distance from the given place.

Bring the given place to the brazen meridian, and screw the quadrant of altitude to the meridian, directly over that place; then, keeping the globe in that position, turn the quadrant quite round upon it, and the degree of the quadrant that touches the second place, will pass over all the other places which are equally distant with it from the given place.

This is the same as if one foot of a pair of compasses was set in the given place, and the other foot extended to the second place, whose distance is known; for if the compasses be then turned round the first place as a center, the moving foot will go over all those places which are at the same distance with the second from it.

the length of a degree ot longitude in geographical miles, and hundredth parts of a mile, for every degree of latitude, from the equator to the poles: a degree on the equator being 60 geographical miles.

ıble shewing the number of miles in a degreee of longitude, in any given degree of latitude. LECT. VIII. & IX.

	Miles. Parts.	Deg.	Miles. Parts.	Deg.	Miles. Parts.
	59.99	31	51.43	61	29.09
	59 96	32	50.88	62	28.17
	59.92	33	50.32	63	27.24
	59.85	34	49.74	64	26.30
	59.77	35	49.15	65	25.36
	59.67	36	48.54	66	24.41
	59.56	37	47.92	67	23.44
	59.42	38	47.28	68	22.48
	59.26	39	46.63	69	21.50
	59.09	40	45.97	70	20.52
	58.89	41	45.28	71	19.53
	58.69	42	44.59	72	18.54
	58.46	43	43.88	73	17.54
	58.22	44	43.16	74	16.53
	57.95	45	42.43	75	15.52
	57.67	46	41.68	76	14.51
	57.38	47	40.92	77	13.50
	57.06	48	40.15	78	12.48
	56.73	49	39.36	79	11.45
	56.38	50	38.57	80	10.42
	56.02	51	37.76	81	9.38
2	55.63	52	36.94	82	8.35
3	55.23	53	36.11	83	7.32
4	54.81	54	35.27	84	6.28
5	54.38	55	34.41	85	5.24
6	53.93	56	33.55	86	4.20
7	53.46	57	32.68	87	3.15
8	52.96	58	31.79	88	2.10
9	52.47	59	30.90	89	1.05
0	51.96	60	30.00	90	0.00

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PROBLEM VIII.

The hour of the day at any place being given, to find all those places where it is noon at that time.

Bring the given place to the brazen meridian, and set the index to the given hour; this done, turn the globe until the index points to the upper XII, and then, all the places that lie under the brazen meridian have noon at that time.

N. B. The upper XII. always stands for noon; and when the bringing of any place to the brazen meridian is mentioned, the side of that meridian on which the degrees are reckoned from the equator is meant, unless the contrary side be mentioned.

PROBLEM IX.

The hour of the day at any place being given, to find what o'clock it then is at any other place.

Bring the given place to the brazen meridian, and set the index to the given hour; then turn the globe, until the place where the hour is required comes to the meridian, and the index will point out the hour at that place.

PROBLEM X.

To find the sun's place in the ecliptic, and his declination,[81] for any given day of the year.

Look on the horizon for the given day, and right against it you have the degree of the sign in which the sun is (or his place) on that day at noon. Find the same degree of that sign in the ecliptic line upon the globe, and having brought it to the brazen meridian,

Note 81. The sun's declination is his distance from the equinoctial in degrees, and is north or south, as the sun is between the equinoctial and the north or south pole.—*Note by the Author.*

've what degree of the meridian stands over it; hat is the sun's declination, reckoned from the :or.

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PROBLEM XI.

'ay of the month being given, to find all those places the earth over which the sun will pass vertically on t day.

ıd the sun's place in the ecliptic for the given day, ıaving brought it to the brazen meridian, observe point of the meridian is over it; then turning the round its axis, all those places which pass under ɔoint of the meridian, are the places required: for eir latitude is equal, in degrees and parts of a e, to the sun's declination, the sun must be di- r over head to each of them at its respective noon.

PROBLEM XII.

ce being given in the torrid zone,[82] to find those two rs of the year, on which the sun shall be vertical to t place.

ıng the given place to the brazen meridian, and the degree of latitude that is exactly over it on eridian; then turn the globe round its axis, and ve the two degrees of the ecliptic which pass ex- under that degree of latitude: lastly, find on the en horizon, the two days of the year on which

82. The globe is divided into five zones; one torrid, two temperate, o frigid. The *torrid zone* lies between the two tropics, and is 47 ı in breadth, or 23½ on each side of the equator: the *temperate* ie between the tropics and polar circles, or from 23½ degrees of ı, to 66½, on each side of the equator; and are each 43 degrees in ı. the *frigid zones* are the spaces included within the polar circles, ɔeing each 23½ degrees from their respective poles, the breadth of these zones is 47 degrees. As the sun never goes without the , he must every moment be vertical to some place or other in the :one.

LECT. VIII.& IX. the sun is in those degrees of the ecliptic, and they are the days required: for on them, and none else, the sun's declination is equal to the latitude of the given place: and consequently, he will then be vertical to it at noon.

PROBLEM XIII.

To find all those places of the north frigid zone, where the sun begins to shine constantly without setting, on any given day, from the 21st of March to the 23d of September.

On these two days, the sun is in the equinoctial, and enlightens the globe exactly from pole to pole: therefore, as the earth turns round its axis, which terminates in the poles, every place upon it will go equally through the light and the dark, and so make the day and night equal to all places of the earth. But as the sun declines from the equator, towards either pole, he will shine just as many degrees round that pole, as are equal to his declination from the equator; so that no place within that distance of the pole will then go through any part of the dark, and consequently the sun will not set to it. Now, as the sun's declination is northward, from the 21st of March to the 23d of September, he must constantly shine round the north pole all that time; and on the day that he is in the northern tropic, he shines upon the whole north frigid zone; so that no place within the north polar circle goes through any part of the dark on that day. Therefore,

Having brought the sun's place for the given day to the brazen meridian, and found his declination (by Prob. IX.) count as many degrees on the meridian, from the north pole, as are equal to the sun's declination from the equator, and mark that degree from the pole where the reckoning ends: then, turning the globe round its axis, observe what places in the north frigid

zone pass directly under that mark; for they are the places required.

The like may be done for the south frigid zone, from the 23d of September to the 21st of March, during which time the sun shines constantly on the south pole.

PROBLEM XIV.

To find the place over which the sun is vertical, at any hour of a given day.

Having found the sun's declination for the given day (by Prob. IX.) mark it with chalk on the brazen meridian; then bring the place where you are (suppose London) to the brazen meridian, and set the index to the given hour; which done, turn the globe on its axis, until the index points to XII at noon; and the place on the globe, which is then directly under the point of the sun's declination marked upon the meridian, has the sun that moment in the zenith, or directly overhead.

PROBLEM XV.

The day and hour at any place being given, to find all those places where the sun is then rising, or setting, or on the meridian: consequently, all those places which are enlightened at that time, and those which are in the dark.

This problem cannot be solved by any globe fitted up in the common way, with the hour circle fixed upon the brass meridian; unless the sun be on or near some of the tropics on the given day. But by a globe fitted up according to Mr. *Joseph Harris's* invention (already mentioned) where the hour-circle lies on the surface of the globe, below the meridian, it may be solved for any day in the year, according to his method; which is as follows:

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Having found the place to which the sun is vertical at the given hour, if the place be in the northern hemisphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of that place; if the place be in the southern hemisphere, elevate the south pole accordingly; and bring the said place to the brazen meridian. Then, all those places which are in the western semicircle of the horizon, have the sun rising to them at that time; and those in the eastern semicircle have it setting: to those under the upper semicircle of the brass meridian, it is noon; and to those under the lower semicircle, it is mid-night. All those places which are above the horizon, are enlightened by the sun, and have the sun just as many degrees high to them, as they themselves are above the horizon: and this height may be known, by fixing the quadrant of altitude on the brazen meridian over the place to which the sun is vertical; and then, laying it over any other place, observe what number of degrees on the quadrant are intercepted between the said place and the horizon. In all those places that are 18 degrees below the western semicircle of the horizon, the morning twilight is just beginning: in all those places that are 18 degrees below the eastern semicircle of the horizon, the evening twilight is ending; and all those places that are lower than 18 degrees, have dark night.

If any place be brought to the upper semicircle of the brazen meridian, and the hour index be set to the upper XII, or noon, and then the globe be turned round eastward on its axis; when the place comes to the western semicircle of the horizon, the index will shew the time of sun-rising at that place; and when the same place comes to the eastern semicircle of the horizon, the index will shew the time of sun-set.

To those places which do not go under the horizon, the sun sets not on that day: and to those which do not come above it, the sun does not rise.

PROBLEM XVI.

The day and hour of a lunar eclipse being given; to find all those places of the earth to which it will be visible.

The moon is never eclipsed but when she is full, and so directly opposite to the sun, that the earth's shadow falls upon her. Therefore, whatever place of the earth the sun is vertical to at that time, the moon must be vertical to the antipodes of that place: so that the sun will be then visible to one half of the earth, and the moon to the other.

Find the place to which the sun is vertical at the given hour (by Prob. XIV.) elevate the pole to the latitude of that place, and bring the place to the upper part of the brazen meridian, as in the former problem: then, as the sun will be visible to all those parts of the globe which are above the horizon, the moon will be visible to all those parts of the globe which are below it, at the time of her greatest obscuration.

But with regard to an eclipse of the sun, there is no such thing as shewing to what places it will be visible, with any degree of certainty, by a common globe; because the moon's shadow covers but a small portion of the earth's surface; and her latitude, or declination from the ecliptic, throws her shadow so variously upon the earth, that to determine the places on which it falls, recourse must be had to long calculations.

PROBLEM XVII.

To rectify the globe for the latitude, the zenith,[83] *and the sun's place.*

Find the latitude of the place (by Prob. I.) and if the place be in the northern hemisphere, raise the north

Note 83. The *zenith*, in this sense, is the highest point of the brazen meridian above the horizon; but in the proper sense, it is that point of the heaven which is directly vertical to any given place, at any given instant of time.—*Note by the Author.*

LECT. VIII.& IX. pole above the north point of the horizon, as many degrees (counted from the pole upon the brazen meridian) as are equal to the latitude of the place. If the place be in the southern hemisphere, raise the south pole above the south point of the horizon, as many degrees as are equal to the latitude. Then, turn the globe till the place comes under its latitude on the brazen meridian, and fasten the quadrant of altitude so, that the chamfered edge of its nut (which is even with the graduated edge) may be joined to the zenith, or point of latitude. This done, bring the sun's place in the ecliptic for the given day, (found by Prob. X.) to the graduated side of the brazen meridian, and set the hour-index to XII at noon, which is the uppermost XII on the hour-circle; and the globe will be rectified.

Remark. The latitude of any place is equal to the elevation of the nearest pole of the heaven above the horizon of that place; and the poles of the heaven are directly over the poles of the earth, each 90 degrees from the equinoctial line. Let us be upon what place of the earth we will, if the limits of our view be not intercepted by hills, we shall see one half of the heaven, or 90 degrees every way round, from that point which is over our heads. Therefore, if we were upon the equator, the poles of the heaven would lie in our horizon, or limit of our view· if we go from the equator, towards either pole of the earth, we shall see the corresponding pole of the heaven rising gradually above our horizon, just as many degrees as we have gone from the equator: and if we were at either of the earth's poles, the corresponding pole of the heaven would be directly over our head. Consequently, the elevation or height of the pole in degrees above the horizon, is equal to the number of degrees that the place is from the equator.

PROBLEM XVIII.

The latitude of any place, not exceeding 66½[84] degrees, and the day of the month, being given; to find the time of sun-rising and setting, and consequently the length of the day and night.

Having rectified the globe for the latitude, and for the sun's place on the given day (as directed in the preceding problem) bring the sun's place in the ecliptic to the eastern side of the horizon, and the hour-index will shew the time of sun-rising; then turn the globe on its axis, until the sun's place comes to the western side of the horizon, and the index will shew the time of sun-setting.

The hour of sun-setting doubled, gives the length of the day; and the hour of sun-rising doubled gives the length of the night.

PROBLEM XIX.

The latitude of any place, and the day of the month, being given; to find when the morning twilight begins, and the evening twilight ends, at that place.

This problem is often limited; for, when the sun does not go 18 degrees below the horizon, the twilight continues the whole night; and for several nights together in summer, between 49 and 66½ degrees of latitude: and the nearer to 66½, the greater is the number of these nights. But when it does begin and end, the following method will shew the time for any given day.

Rectify the globe, and bring the sun's place in the ecliptic to the eastern side of the horizon; then mark

Note 84. All places whose latitude is more than 66½ degrees, are in the frigid zones: and to those places the sun does not set in summer, for a certain number of diurnal revolutions, which occasions this limitation of latitude.—*Note by the Author.*

LECT. VIII. that point of the ecliptic with a chalk which is in the western side of the horizon, it being the point opposite to the sun's place. This done, lay the quadrant of altitude over the said point, and turn the globe eastward, keeping the quadrant at the chalk-mark, until it is just 18 degrees high on the quadrant; and the index will point out the time when the morning twilight begins: for the sun's place will then be 18 degrees below the eastern side of the horizon. To find the time when the evening twilight ends, bring the sun's place to the western side of the horizon, and the point opposite to it, which was marked with the chalk, will be rising in the east. Then, bring the quadrant over that point, and keeping it thereon, turn the globe westward, until the said point be 18 degrees above the horizon on the quadrant, and the index will shew the time when the evening twilight ends: the sun's place being then 18 degrees below the western side of the horizon.

PROBLEM XX.

To find on what day of the year the sun begins to shine constantly without setting, on any given place in the north frigid zone; and how long he continues to do so.

Rectify the globe to the latitude of the place, and turn it about until some point of the ecliptic, between *Aries* and *Cancer* coincides with the north point of the horizon where the brazen meridian cuts it: then find, on the wooden horizon, what day of the year the sun is in that point of the ecliptic: for that is the day on which the sun begins to shine constantly on the given place, without setting. This done, turn the globe until some point of the ecliptic, between *Cancer* and *Libra*, coincides with the north point of the horizon, where the brazen meridian cuts it; and find, on the wooden horizon, on what day the sun is in that point of the ecliptic; which is the day that the sun leaves off constantly shin-

ing on the said place, and rises and sets to it as to other places on the globe. The number of natural days, or complete revolutions of the sun about the earth, between the two days above found, is the time that the sun keeps constantly above the horizon without setting: for all the portions of the ecliptic, that lie between the two points which intersect the horizon in the very north, never sets below it: and there is just as much of the opposite part of the ecliptic that never rises; therefore, the sun will keep as long constantly below the horizon in winter, as above it in summer.

Whoever considers the globe, will find, that all places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally deprived of it. For, the days and nights are always equally long at the equator: and in all places that have latitude, the days at one time of the year are exactly equal to the nights at the opposite season.

PROBLEM XXI.

To find in what latitude the sun shines constantly without setting, for any length of time less than 182½[85] *of our days and nights.*

Find a point in the ecliptic half as many degrees from the beginning of *Cancer* (either towards *Aries* or *Libra*) as there are natural days[86] in the time given; and bring that point to the north side of the brazen meridian, on which the degrees are numbered from the pole towards the equator: then, keep the globe from turning on its axis, and slide the meridian up or down, until the foresaid point of the ecliptic comes to the north point of the

Note 85. The reason of this limitation is, that 182½ of our days and nights make half a year, which is the longest time that the sun shines without setting, even at the poles of the earth.—*Note by the Author.*

Note 86. A natural day contains the whole 24 hours: an artificial day, the time that the sun is above the horizon.—*Ibid.*

LECT. VIII & IX. horizon, and then, the elevation of the pole will be equal to the latitude required.

PROBLEM XXII.

The latitude of a place, not exceeding 66½ degrees, and the day of the month being given; to find the sun's amplitude, or point of the compass on which he rises or sets.

Rectify the globe, and bring the sun's place to the eastern side of the horizon; then observe what point of the compass on the horizon stands right against the sun's place, for that is his amplitude at rising. This done, turn the globe westward, until the sun's place comes to the western side of the horizon, and it will cut the point of his amplitude at setting. Or, you may count the rising amplitude in degrees, from the east point of the horizon, to that point where the sun's place cuts it; and the setting amplitude, from the west point of the horizon, to the sun's place at setting.

PROBLEM XXIII.

The latitude, the sun's place, and his altitude,[a] *being given; to find the hour of the day, and the sun's azimuth, or number of degrees that he is distant from the meridian.*

Rectify the globe, and bring the sun's place to the given height upon the quadrant of altitude; on the eastern side of the horizon, if the time be in the forenoon; or the western side, if it be in the afternoon; then, the index will shew the hour; and the number of degrees in the horizon intercepted between the quadrant of altitude and the south point, will be the sun's true azimuth at that time.

N. B. Always when the quadrant of altitude is men-

Note 87. The sun's altitude, at any time, is his height in degrees above the horizon at that time.—*Note by the Author.*

tioned in working any problem, the graduated edge of it is meant.

If this be done at sea, and compared with the sun's azimuth, as shewn by the compass, if they agree, the compass has no variation in that place: but if they differ, the compass does vary; and the variation is equal to this difference.

PROBLEM XXIV.

The latitude, hour of the day, and the sun's place, being given; to find the sun's altitude and azimuth.

Rectify the globe, and turn it until the index points to the given hour; then lay the quadrant of altitude over the sun's place in the ecliptic, and the degree of the quadrant cut by the sun's place is his altitude at that time above the horizon; and the degree of the horizon cut by the quadrant is the sun's azimuth, reckoned from the south.

PROBLEM XXV.

The latitude, the sun's altitude, and his azimuth being given; to find his place in the ecliptic, the day of the month, and hour of the day, though they had all been lost.

Rectify the globe for the latitude and zenith,[88] and set the quadrant of altitude to the given azimuth in the horizon; keeping it there, turn the globe on its axis until the ecliptic cuts the quadrant in the given altitude: that point of the ecliptic which cuts the quadrant there, will be the sun's place; and the day of the month answering thereto, will be found over the like place of the sun on the wooden horizon. Keep the quadrant of altitude in that position, and having brought the sun's

Note 88. By rectifying the globe for the zenith, is meant screwing the quadrant of altitude to the given latitude on the brass meridian.—*Note by the Author.*

LECT. VIII. place to the brazen meridian, and the hour index to XII at noon. Then turn the globe, until the sun's place cuts the quadrant of altitude again, and the index will shew the hour.

Any two points of the ecliptic which are equi-distant from the beginning of *Cancer* or of *Capricorn*, will have the same altitude and azimuth at the same hour, though the months be different: and therefore it requires some care in this problem, not to mistake both the month and the day of the month: to avoid which, observe, that from the 20th of March to the 21st of June, that part of the ecliptic which is between the beginning of *Aries* and beginning of *Cancer* is to be used: from the 21st of June to the 23d of September, between the beginning of *Cancer* and beginning of *Libra*: from the 23d of September to the 21st of December, between the beginning of *Libra* and the beginning of *Capricorn*; and from the 21st of December to the 20th of March, between the beginning of *Capricorn* and beginning of *Aries*. And as one can never be at a loss to know in what quarter of the year he takes the sun's altitude and azimuth, the above caution with regard to the quarters of the ecliptic, will keep him right as to the month and day thereof.

PROBLEM XXVI.

To find the length of the longest day at any given place.

If the place be on the north side of the equator, find its latitude (by Prob. I.) and elevate the north pole to that latitude; then, bring the beginning of *Cancer* ♋ to the brazen meridian, and set the hour index to XII at noon. But if the given place be on the south side of the equator, elevate the south pole to its latitude, and bring the beginning of *Capricorn* ♑ to the brass meridian, and the hour-index to XII. This done, turn the globe westward, until the beginning of *Cancer* or *Ca-*

pricorn (as the latitude is north or south) comes to the horizon; and the index will then point out the time of sun-setting, for it will have gone over all the afternoon hours, between mid-day and sun-set; which length of time being doubled, will give the whole length of the day, from sun-rising to sun-setting. For, in all latitudes, the sun rises as long before mid-day, as he sets after it.

PROBLEM XXVII.

To find in what latitude the longest day is of any given length less than 24 hours.

If the latitude be north, bring the beginning of *Cancer* to the brazen meridian, and elevate the north pole to about 66½ degrees; but if the latitude be south, bring the beginning of *Capricorn* to the meridian, and elevate the south pole to about 66½ degrees: because the longest day in north latitude, is when the sun is in the first point of *Cancer:* and in south latitude, when he is in the first point of *Capricorn.* Then set the hour-index to XII at noon, and turn the globe westward, until the index points at half the number of hours given: which done, keep the globe from turning on its axis, and slide the meridian down in the notches, until the aforesaid point of the ecliptic (viz. *Cancer* or *Capricorn*) comes to the horizon; then, the elevation of the pole will be equal to the latitude required.

PROBLEM XXVIII.

The latitude of any place, not exceeding 66½ degrees, being given, to find in what climate[89] *the place is.*

Find the length of the longest day at the given place by Prob. XXVI. and whatever be the number of hours

Note 89. A *climate*, from the equator to either of the polar circles, is a tract of the earth's surface, included between two such parallels

LECT. VIII. & IX. whereby it exceedeth twelve, double that number, and the sum will answer to the climate in which the place is.

PROBLEM XXIX.

The latitude, and the day of the month, being given; to find the hour of the day when the sun shines.

Set the wooden horizon truly level, and the brass meridian due north and south by a mariner's compass: then, having rectified the globe, stick a small sewing-needle into the sun's place in the ecliptic, perpendicular to that part of the surface of the globe: this done, turn the globe on its axis, until the needle comes to the brazen meridian, and set the hour-index to XII at noon; then, turn the globe on its axis, until the needle points exactly towards the sun (which it will do when it casts no shadow on the globe) and the index will shew the hour of the day.

PROBLEM XXX.

A pleasant way of shewing all those places of the earth which are enlightened by the sun, and also the time of the day when the sun shines.

Take the terrestrial ball out of the wooden horizon, and also out of the brazen meridian; then set it upon a pedestal in sun-shine, in such a manner, that its north pole may point directly towards the north pole of the heaven, and the meridian of the place where you are, be directly towards the south. Then, the sun will shine upon all the like places of the globe, that he does on the

of latitude, that the length of the longest day in the one exceeds that in the other by half an hour; but from the polar circles to the poles, where the sun keeps long above the horizon without setting, each climate differs a whole month from the one next to it. There are twenty-four climates between the equator and each of the polar circles; and six from each polar circle to its respective pole.—*Note by the Author.*

real earth, rising to some when he is setting to others; as you may perceive by that part where the enlightened half of the globe is divided from the half in the shade, by the boundary of the light and darkness; all those places, on which the sun shines, at any time, having day; and all those, on which he does not shine, having night. LECT. VIII.&IX.

If a narrow slip of paper be put round the equator, and divided into 24 equal parts, beginning at the meridian of your place, and the hours be set to those divisions in such a manner, that one of the VI's may be upon your meridian; the sun being upon that meridian at noon, will then shine exactly to the two XII's; and at one o'clock to the two I's, &c. So that the place, where the enlightened half of the globe is parted from the shaded half, in this circle of hours, will shew the hour of the day.

The principles of dialing shall be explained farther on, by the terrestrial globe. At present we shall only add the following observations upon it; and then proceed to the use of the celestial globe.

1. The latitude of any place is equal to the elevation of the pole above the horizon of that place, and the elevation of the equator is equal to the complement of the latitude, that is, to what the latitude wants of ninety degrees.

2. Those places which lie on the equator have no latitude, it being there that the latitude begins; and those places which lie on the first meridian have no longitude, it being there that the longitude begins. Consequently, that particular place of the earth where the first meridian intersects the equator, has neither longitude nor latitude.

3. In all places of the earth, except the poles, all the points of the compass may be distinguished in the horizon: but from the north pole, every place is south;

PLATE. VIII. & IX. and from the south pole every place is north. Therefore as the sun is constantly above the horizon of each pole for half a year in its turn, he cannot be said to depart from the meridian of either pole for half a year together. Consequently, at the north pole it may be said to be noon every moment for half a year; and let the winds blow from what part they will, they must always blow from the south: and at the south pole, from the north.

4. Because one half of the ecliptic is above the horizon of the pole, and the sun, moon, and planets, move in or nearly in the ecliptic; they will all rise and set to the poles. But, because the stars never change their declinations from the equator (at least not sensibly in one age) those which are once above the horizon of either pole, never set below it: and those which are once below it, never rise.

5. All places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally deprived of it.

6. All places upon the equator have their days and nights equally long, that is, 12 hours each, at all times of the year. For although the sun declines alternately from the equator towards the north and towards the south: yet as the horizon of the equator cuts all the parallels of latitude and declination in halves, the sun must always continue above the horizon for one half a diurnal revolution about the earth, and for the other half below it.

7. When the sun's declination is greater than the latitude of any place, upon either side of the equator, the sun will come twice to the same azimuth or point of the compass in the forenoon, at that place; and twice to a like azimuth in the afternoon; that is, he will go twice back every day, whilst his declination continues to be greater than the latitude. Thus suppose the globe rectified to the latitude of Barbadoes, which is 13 degrees

north; and the sun to be any where in the ecliptic, between the middle of Taurus and the middle of Leo; if the quadrant of altitude be set to about[90] 19 degrees north of the east in the horizon, the sun's place be marked with a chalk upon the ecliptic, and the globe be then turned westward on its axis, the said mark will rise in the horizon a little to the north of the quadrant, and thence ascending, it will cross the quadrant towards the south; but before it arrives at the meridian, it will cross the quadrant again and pass over the meridian northward of Barbadoes. And if the quadrant be set about 18 degrees north of the west, the sun's place will cross it twice, as it descends from the meridion towards the horizon, in the afternoon.

8. In all places of the earth between the equator and poles, the days and nights are equally long, viz. 12 hours each, when the sun is in the equinoctial: for, in all elevations of the pole, short of 90 degrees (which is the greatest) one half of the equator or equinoctial will be above the horizon, and the other half below it.

9. The days and nights are never of an equal length at any place between the equator and polar circles, but when the sun enters the signs ♈ Aries and ♎ Libra. For in every other part of the ecliptic, the circle of the sun's daily motion is divided into two unequal parts by the horizon.

10. The nearer that any place is to the equator, the less is the difference between the length of the days and nights in that place; and the more remote, the contrary. The circles which the sun describes in the heaven every 24 hours, being cut more nearly equal in the former case, and more unequally in the latter.

11. In all places lying upon any given parallel of latitude, however long or short the day or night be at any one of these places, at any time of the year, it is

Note 90. From the middle of Gemini to the middle of Cancer, the quadrant may be set 20 degrees. *Note by the Author.*

then of the same length at all the rest; for in turning the globe round its axis (when rectified according to the sun's declination) all these places will keep equally long above or below the horizon.

12. The sun is vertical twice a year to every place between the tropics; to those under the tropics, once a year, but never any where else. For, there can be no place between the tropics, but that there will be two points in the ecliptic, whose declination from the equator is equal to the latitude of that place; and but one point of the ecliptic which has a declination equal to the latitude of places on the tropic which that point of the ecliptic touches; and as the sun never goes without the tropics, he can never be vertical to any place that lies without them.

13. To all places in the torrid zone,[91] the duration of the twilight is least, because the sun's daily motion is the most perpendicular to the horizon. In the frigid zones,[92] greatest; because the sun's daily motion is nearly parallel to the horizon; and therefore he is the longer of getting 18 degrees below it (till which time the twilight always continues.) And in the temperate zones,[93] it is at a medium between the two, because the obliquity of the sun's daily motion is so.

14. In all places lying exactly under the polar circles, the sun, when he is in the nearest tropic, continues 24 hours above the horizon without setting; because no part of that tropic is below their horizon. And when the sun is in the farthest tropic, he is for the same length of time without rising; because no part of that tropic is above their horizon. But, at all other times of the year, he rises and sets there, as in other places; because all the circles that can be drawn parallel to the equator, between the tropics, are more or less cut by the

Note 91. Between the tropics. *Note by the Author.*
Note 92. Between the polar circles and poles. *Ibid.*
Note 93. Between the tropics and polar circles. *Ibid.*

·izon, as they are farther from, or nearer to, that LECT. VIII.&IX.
pic which is all above the horizon: and when the sun not in either of the tropics, his diurnal course must in one or other of these circles.

15. To all places in the northern hemisphere, from equator to the polar circle, the longest day and ›rtest night is when the sun is in the northern tropic; 1 the shortest day and longest night is when the sun in the southern tropic; because no circle of the sun's ly motion is so much above the horizon, and so little ow it, as the northern tropic; and none so little above and so much below it, as the southern. In the sou- rn hemisphere, the contrary.

16. In all places between the polar circles and poles, sun appears for some number of days (or rather ırnal revolutions) without setting; and at the oppo- e time of the year without rising; because some part the ecliptic never sets in the former case, and as ıch of the opposite part never rises in the latter. And nearer unto, or the more remote from the pole, these ıces are, the longer or shorter is the sun's continuing esence or absence.

17. If a ship sets out from any port, and sails round earth eastward to the same port again, let her take ıat time she will to do it in, the people in that ship, reckoning their time, will gain one complete day at ›ir return, or count one day more than those who re- le at the same port; because, by going contrary to sun's diurnal motion, and being forwarder every ening than they were in the morning, their horizon ll get so much the sooner above the setting sun, than they had kept for a whole day at any particular place. ıd thus, by cutting off a part proportionable to their rn motion, from the length of every day, they will ıin a complete day of that sort at their return; without ıining one moment of absolute time more than is apsed during their course, to the people at the port.

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If they sail westward, they will reckon one day less than the people do who reside at the said port, because by gradually following the apparent diurnal motion of the sun, they will keep him each particular day so much longer above their horizon, as answers to that day's course; and by that means, they cut off a whole day in reckoning, at their return, without losing one moment of absolute time.

Hence, if two ships should set out at the same time from any port, and sail round the globe, one eastward and the other westward, so as to meet at the same port on any day whatever; they will differ two days in reckoning their time, at their return. If they sail twice round the earth, they will differ four days; if thrice, then six, &c.[94]

Note 94. A reference to the printed Journals of Vancouver, Cook, &c. will sufficiently shew the truth of this position, which affords an additional illustration of the earth's rotundity.

LECT X.

LECTURE X.

THE USE OF THE CELESTIAL GLOBE, AND ARMILLARY SPHERE.

HAVING done for the present with the terrestrial globe, we shall proceed to the use of the celestial; first premising, that as the equator, ecliptic, tropics, polar circles, horizon, and brazen meridian, are exactly alike on both globes, all the former problems concerning the sun are solved the same way by both globes. The method also of rectifying the celestial globe is the same as rectifying the terrestrial, viz. Elevate the pole according to the latitude of your place, then screw the quadrant of altitude to the zenith, on the brass meridian; bring the sun's place in the ecliptic to the graduated edge of the brass meridian, on the side which is above the south point of the wooden horizon, and set the hour-index to the uppermost XII, which stands for noon. *The celestial globe.* *To rectify it.*

N. B. The sun's place for any day of the year stands directly over that day on the horizon of the celestial globe, as it does on that of the terrestrial.

The *latitude* and *longitude* of the stars, and of all other celestial phænomena, are reckoned in a very different manner from the latitude and longitude of places on the earth: for all terrestrial latitudes are reckoned from the equator; and longitudes from the meridian of some remarkable place, as of London by the English, and of Paris by the French; though most of the French maps begin their longitude at the meridian of the island *Ferro.* But the astronomers of all nations agree in reckoning the *latitudes* of the moon, stars, planets, and comets, from the *ecliptic;* and their *longitudes* from the *equinoctial colure,*[95] *Latitude and longitude of the stars.*

Note 95. *The great circle* that passes through the *equinoctial points* at the beginning of *Taurus* and *Libra*, and through the *poles of the*

LECT. X.

in that semicircle of it which cuts the ecliptic at the beginning of *Aries* ♈; and thence eastward, quite round, to the same semicircle again. Consequently those stars which lie between the equinoctial and the northern half of the ecliptic, have north declination and south latitude; those which lie between the equinoctial and the southern half of the ecliptic, have south declination and north latitude; and all those which lie between the tropics and poles, have their declinations and latitudes of the same denomination. There are six great circles on the celestial globe, which cut the ecliptic perpendicularly, and meet in two opposite points in the polar circles; which points are each ninety degrees from the ecliptic, and are called its poles. These polar points divide those circles into 12 semicircles; which cut the ecliptic at the beginnings of the 12 signs. They resemble so many meridians on the terrestrial globe; and as all places which lie under any particular meridian semicircle on that globe, have the same longitude, so all those points of the heaven, through which any one of the above semicircles are drawn, have the same longitude.—And as the greatest latitudes on the earth are at the north and south poles of the earth, so the greatest latitudes in the heaven, are at the north and south poles of the ecliptic.

Constellations.

In order to distinguish the stars, with regard to their situations and positions in the heaven, the ancients divided the whole visible firmament of stars into particular systems, which they called *constellations;* and digested them into the forms of such animals as are delineated upon the celestial globe. And those stars which lie between the figures of those imaginary animals, and could

world (which are two opposite points, each 90 degrees from the equinoctial,) is called the *equinoctial colure:* and the *great circle* that passes through the *beginning of* Taurus and *Libra*, and also through the *poles of the ecliptic*, and poles of the world, is called the *solstitial colure*.

Colures.

not be brought within the compass of any of them, were called *unformed stars*. LECT. X.

Because the moon and all the planets were observed to move in circles or orbits which cross the ecliptic (or line of the sun's path) at small angles, and to be on the north side of the ecliptic for one half of their course round the heaven of stars, and on the south side of it for the other half, but never to go quite 8 degrees from it on either side, the ancients distinguished that space by two lesser circles, parallel to the ecliptic (one on each side) at 8 degrees distance from it. And the space included between these circles, they called the *zodiac*, because most of the 12 constellations placed therein resemble some living creature.—These constellations are, 1. *Aries* ♈, the ram; 2. *Taurus* ♉, the bull; 3. *Gemini* ♊, the twins; 4. *Cancer* ♋, the crab; 5. *Leo* ♌, the lion; 6. *Virgo* ♍, the virgin; 7. *Libra* ♎, the balance; 8. *Scorpio* ♏, the scorpion; 9. *Sagittarius* ♐, the archer; 10. *Capricornus* ♑, the goat; 11. *Aquarius* ♒, the water bearer; and 12. *Pisces* ♓, the fishes. Its signs or divisions.

Remark. It is to be observed, that in the infancy of astronomy, these twelve constellations stood at or near the places of the ecliptic, where the above characteristics are marked upon the globe: but now, each constellation has got a whole sign forwarder, on account of the recession of the equinoctial points from their former places. So that the constellation of *Aries*, is now in the former place of *Taurus*; that of *Taurus*, in the former place of *Gemini*; and so on.

The stars appear of different magnitudes to the eye; probably because they are at different distances from us. Those which appear brightest and largest, are called *stars of the first magnitude;* the next to them in size and lustre, are called *stars of the second magnitude;* and so on to the *sixth*, which are the smallest that can be discerned by the bare eye.

Some of the most remarkable stars have names given

LECT. X. them, as *Castor* and *Pollux* in the heads of the *Twins*, *Sirius* in the mouth of the *Great Dog*, *Procyon* in the side of the *Little Dog*, *Rigel* in the left foot of *Orion*, *Arcturus* near the right thigh of *Bootes*, &c.

These things being premised, which I think are all that the young *Tyro* need be acquainted with, before he begins to work any problem with this globe, we shall now proceed to the most useful of those problems; omitting several which are of little or no consequence.

PROBLEM I.

To find the right ascension[96] *and declination*[97] *of the sun, or any fixed star.*

Bring the sun's place in the ecliptic to the brazen meridian, then that degree in the equinoctial which is cut by the meridian, is the sun's *right ascension*; and that degree of the meridian which is over the sun's place, is his *declination.* Bring any fixed star to the meridian, and its *right ascension* will be cut by the meridian in the equinoctial; and the degree of the meridian that stands over it, is its *declination.*

So that *right ascension* and *declination*, on the celestial globe, are found in the same manner as *longitude* and *latitude* on the terrestrial.

PROBLEM II.

To find the latitude and longitude of any star.

If the given star be on the north side of the ecliptic, place the 90th degree of the quadrant of altitude on the north pole of the ecliptic, where the twelve semicircles

Note 96. The degree of the equinoctial, reckoned from the beginning of *Aries*, that comes to the meridian with the sun or star, is its *right ascension.—Note by the Author.*

Note 97. The distance of the sun or star in degrees from the equinoctial, towards either of the poles, north or south, is its declination, which is north or south accordingly.—*Ibid.*

meet; which divide the ecliptic into the 12 signs: but if the star be on the south side of the ecliptic, place the 90th degree of the quadrant on the south pole of the ecliptic: keeping the 90th degree of the quadrant on the proper pole, turn the quadrant about, until its graduated edge cuts the star: then, the number of degrees in the quadrant, between the ecliptic and the star, is its latitude; and the degree of the ecliptic cut by the quadrant is the star's longitude, reckoned according to the sign in which the quadrant then is. LECT. X.

PROBLEM III.

To represent the face of the starry firmament, as seen from any given place of the earth, at any hour of the night.

Rectify the celestial globe for the given latitude, the zenith, and sun's place, in every respect, as taught by the 17th problem, for the terrestrial; and turn it about, until the index points to the given hour: then, the upper hemisphere of the globe will represent the visible half of the heaven for that time; all the stars upon the globe being then in such situations, as exactly correspond to those in the heaven. And if the globe be placed duly north and south, by means of a small sea-compass, every star on the globe will point towards the like star in the heaven: by which means, the constellations and remarkable stars may be easily known. All those stars which are in the eastern side of the horizon, are then rising in the eastern side of the heaven; all in the western, are setting in the western side; and all those under the upper part of the brazen meridian, between the south point of the horizon and the north pole, are at their greatest altitude, if the latitude of the place be north: but if the latitude be south, those stars which lie under the upper part of the meridian, between the north point of the horizon and the south pole, are at their greatest altitude.

PROBLEM IV.

The latitude of the place, and day of the month, being given; to find the time when any known star will rise, or be on the meridian, or set.

Having rectified the globe, turn it about until the given star comes to the eastern side of the horizon, and the index will shew the time of the star's rising; then turn the globe westward, and when the star comes to the brazen meridian, the index will shew the time of the star's coming to the meridian of your place; lastly, turn on, until the star comes to the western side of the horizon, and the index will shew the time of the star's setting.

N. B. In northern latitudes, those stars which are less distant from the north pole, than the quantity of its elevation above the north point of the horizon, never set; and those which are less distant from the south pole, than the number of degrees by which it is depressed below the horizon, never rise; and *vice versâ* in southern latitudes.

PROBLEM V.

To find at what time of the year a given star will be upon the meridian, at a given hour of the night.

Bring the given star to the upper semicircle of the brass meridian, and set the index to the given hour; then turn the globe, until the index points to XII at noon, and the upper semicircle of the meridian will then cut the sun's place, answering to the day of the year sought; which day may be easily found against the like place of the sun among the signs on the wooden horizon.

PROBLEM VI.

The latitude, day of the month, and azimuth[98] *of any known star being given; to find the hour of the night.*

Having rectified the globe for the latitude, zenith, and sun's place: lay the quadrant of altitude to the given degree of azimuth in the horizon: then turn the globe on its axis, until the star comes to the graduated edge of the quadrant; and when it does, the index will point out the hour of the night.

PROBLEM VII.

The latitude of the place, the day of the month, and altitude[99] *of any known star, being given; to find the hour of the night.*

Rectify the globe as in the former problem, guess at the hour of the night, and turn the globe until the index points at the supposed hour; then lay the graduated edge of the quadrant of altitude over the known star, and if the degree of the star's height in the quadrant upon the globe, answers exactly to the degree of the star's observed altitude in the heaven, you have guessed exactly: but if the star on the globe is higher or lower than it was observed to be in the heaven, turn the globe backwards or forwards, keeping the edge of the quadrant upon the star, until its center comes to the observed altitude in the quadrant; and then, the index will shew the true time of the night.

Note 98. The number of the degrees that the sun, moon, or any star, is from the meridian, either to the east or west, is called its *azimuth.—Note by the Author.*

Note 99. The number of degrees that the star is above the horizon, as observed by means of a common quadrant, is called its *altitude.—Ibid.*

LECT. X.

PROBLEM VIII.

An easy method for finding the hour of the night by any two known stars, without knowing either their altitude or azimuth; and then, of finding both their altitude and azimuth, and thereby the true meridian.

Tie one end of a thread to a common musket bullet; and, having rectified the globe as above, hold the other end of the thread in your hand, and carry it slowly round betwixt your eye and the starry heaven, until you find it cuts any two known stars at once. Then, guessing at the hour of the night, turn the globe until the index points to that time in the hour circle: which done, lay the graduated edge of the quadrant over any one of those two stars on the globe, which the thread cuts in the heavens. If the said edge of the quadrant cuts the other star also, you have guessed the time exactly; but if it does not, turn the globe slowly backwards or forwards, until the quadrant (kept upon either star) cuts them both through their centers: and then, the index will point out the exact time of the night; the degree of the horizon, cut by the quadrant, will be the true azimuth of both these stars from the south; and the stars themselves will cut their true altitudes in the quadrant. At which moment, if a common azimuth compass be so set upon a floor or level pavement, that these stars in the heaven may have the same bearing upon it (allowing for the variation of the needle) as the quadrant of altitude has in the wooden horizon of the globe, a thread extended over the north and south points of that compass will be directly in the plane of the meridian: and if a line be drawn upon the floor or pavement, along the course of the thread, and an upright wire be placed in the southmost and of the line, the shadow of the wire will fall upon that line, when the sun is on the meridian, and shines upon the pavement.

PROBLEM IX.

To find the place of the moon, or of any planet; and thereby to shew the time of its rising, southing, and setting.

Seek in *Parker's* or *White's* Ephemeris the geocentric place[100] of the moon or planet in the ecliptic, for the given day of the month; and, according to its longitude and latitude, as shewn by the Ephemeris, mark the same with a chalk upon the globe. Then, having rectified the globe, turn it round its axis westward; and as the said mark comes to the eastern side of the horizon, to the brazen meridian, and to the western side of the horizon, the index will shew at what time the planet rises, comes to the meridian, and sets, in the same manner as it would do for a fixed star.

PROBLEM X.

To explain the phenomena of the harvest-moon.

In order to do this, we must premise the following things. 1. That as the sun goes only once a year round the ecliptic, he can be but once a year in any particular point of it: and that his motion is almost a degree every 24 hours, at a mean rate. 2. That as the moon goes round the ecliptic once in 27 days and 8 hours, she advances 13⅕ degrees in it, every day at a mean rate. 3. That as the sun goes through part of the ecliptic in the time the moon goes round it, the moon cannot at any time be either in conjunction with the sun, or opposite to him, in that part of the ecliptic where she was so the last time before; but must travel as much forwarder, as the sun has advanced in the said time; which being 29½ days, makes almost a whole

Note 100. The place of the moon or planet, as seen from the earth, is called its geocentric place.--*Note by the Author*

LECT. X. sign. Therefore, 4. The moon can be but once a year opposite to the sun, in any particular part of the ecliptic. 5. That the moon is never full but when she is opposite to the sun, because at no other time can we see all that half of her, whieh the sun enlightens. 6. That when any point of the ecliptic rises, the opposite point sets. Therefore, when the moon is opposite to the sun, sh must rise at sun-set.[101] 7. That the different signs of the ecliptic rise at very different angles or degrees of obliquity with the horizon, especially in considerable latitudes; and that the smaller this angle is, the greater is the portion of the ecliptic that rises in any small small part of time; and *vice versâ*. 8. That, in northern latitudes, no part of the ecliptic rises at so small ac angle with the horizon, as *Pisces* and *Aries* do; therefore, a greater portion of the ecliptic rises in one hour, about these signs, than about any of the rest. 9. That the moon can never be full in *Pisces* and *Aries* but in our autumnal months, for at no other time of the year is the sun in the opposite signs *Virgo* and *Libra*.

These things premised, take 13⅕ degrees of the ecliptic in your compasses, and beginning at *Pisces*, carry that extent all round the ecliptic, marking the places with a chalk, where the points of the compasses successively fall. So you will have the moon's daily motion marked out for one complete revolution in the ecliptic (according to § 2 of the last paragraph.)

Rectify the globe for any considerable northern latitude, (as suppose that of London) and then, turning the globe round its axis, observe how much of the hour-circle the index has gone over, at the rising of each particular mark on the ecliptic; and you will find that seven of the marks (which take in as much of the ecliptic as

Note 101. This is not always true, because the moon does not keep in the ecliptic, but crosses it twice every month. However, the difference need not be regarded in a general explanation.—*Note by the Author.*

the moon goes through in a week) will all rise successively about *Pisces* and *Aries*, in the time that the index goes over two hours. Therefore, whilst the moon is in *Pisces* and *Aries*, she will not differ in general above two hours in her rising for a whole week. But if you take notice of the marks on the opposite signs, *Virgo* and *Libra*, you will find that seven of them take nine hours to rise; which shews, that when the moon is in these two signs, she differs nine hours in her rising within the compass of a week. And so much later as every mark is of rising than the one that rose next before it, so much later will the moon be of rising on any day than she was on the day before, in the corresponding part of the heaven. The marks about *Cancer* and *Capricorn* rise at a mean difference of time between those about *Aries* and *Libra*.

Now, although the moon is in *Pisces* and *Aries* every month, and therefore must rise in those signs within the space of two hours later for a whole week, or only about seventeen minutes later every day than she did on the former; yet she is never full in these signs, but in our autumnal months, *August* and *September*, when the sun is in *Virgo* and *Libra*. Therefore, no full moon in the year will continue to rise so near the time of sun-set for a week or so, as these two full moons do, which fall in the time of harvest.

In the winter months, the moon is in *Pisces* and *Aries* about her first quarter: and as these signs rise about noon in winter, the moon's rising in them passes unobserved. In the spring months, the moon changes in these signs, and consequently rises at the same time with the sun; so that it is impossible to see her at that time. In the summer months she is in these signs about her third quarter, and rises not until midnight, when her rising is but very little taken notice of; especially as she is on the decrease. But in the harvest months she is at the full, when in these signs, and being opposite to

the sun, she rises when the sun sets (or soon after, and shines all the night.

In southern latitudes, *Virgo* and *Libra* rise at as small angles with the horizon, as *Pisces* and *Aries* do in the northern; and as our spring is at the time of their harvest, it is plain their harvest full moons must be in *Virgo* and *Libra*; and will therefore rise with as little difference of time, as ours do in *Pisces* and *Aries*.

For a fuller account of this matter, I must refer the reader to my Astronomy, in which it is described at large.

PROBLEM XI.

To explain the equation of time, or difference of time between well regulated clocks and true sun-dials.

The earth's motion on its axis being perfectly equable, and thereby causing an apparent equable motion of the starry heaven round the same axis, produced to the poles of the heaven; it is plain that equal portions of the celestial equator pass over the meridian in equal parts of time, because the axis of the world is perpendicular to the plane of the equator. And therefore, if the sun kept his annual course in the celestial equator, he would always revolve from the meridian to the meridian again in twenty-four hours exactly, as shewn by a well-regulated clock.

But as the sun moves in the ecliptic, which is oblique both to the plane of the equator and axis of the world, he cannot always revolve from the meridian to the meridian again in 24 equal hours; but sometimes a little sooner, and at other times a little later, because equal portions of the ecliptic pass over the meridian in unequal parts of time, on account of its obliquity. And this difference is the same in all latitudes.

To shew this by a globe, make chalk-marks all around the equator and ecliptic, at equal distances from

Pl.

Fig. 3

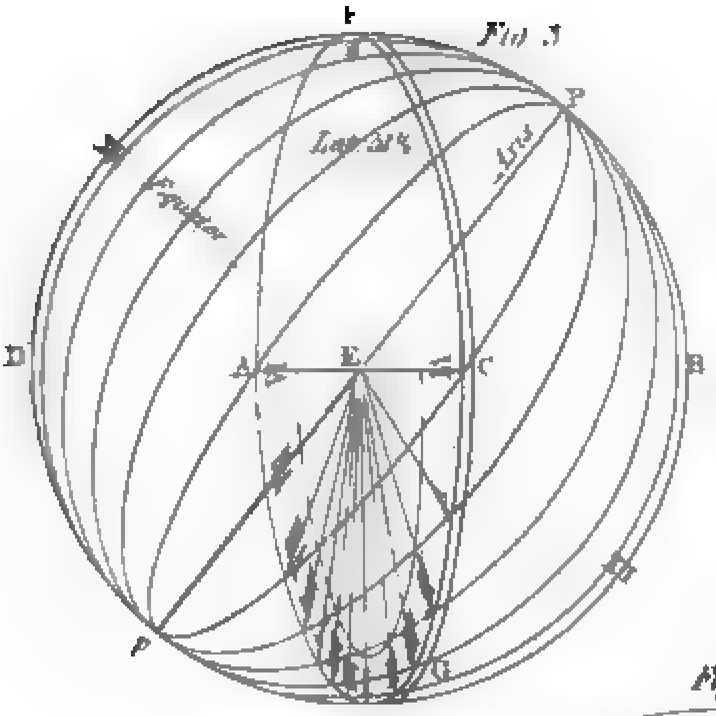


Fig. 2

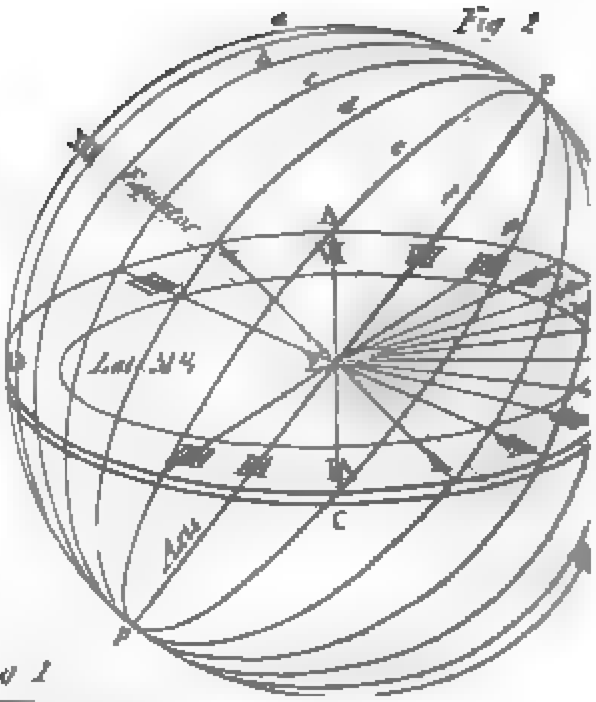
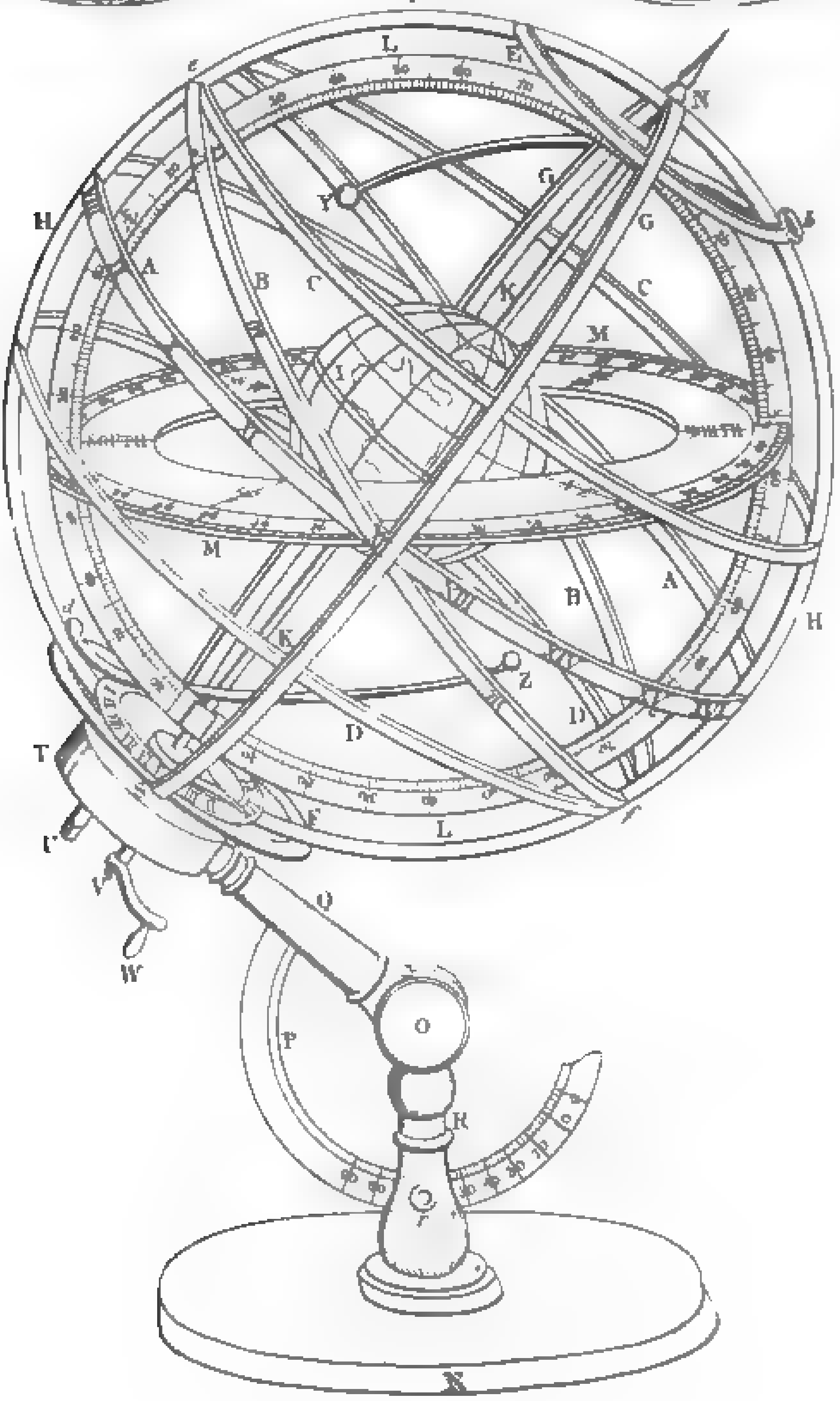


Fig. 1



one another (suppose 10 degrees) beginning at *Aries* or at *Libra*, where these two circles intersect each other. Then turn the globe round its axis, and you will see that all the marks in the first quadrant of the ecliptic, or from the beginning of *Aries* to the beginning of *Cancer*, come sooner to the brazen meridian than their corresponding marks do on the equator: those in the second quadrant, or from the beginning of *Cancer* to the beginning of *Libra*, come later; those in the third quadrant, from *Libra* to *Capricorn*, sooner; and those in the fourth, from *Capricorn* to *Aries*, later. But those at the beginning of each quadrant come to the meridian at the same time with their corresponding marks on the equator.

Therefore, whilst the sun is in the first and third quadrants of the ecliptic, he comes sooner to the meridian every day than he would do if he kept in the equator; and consequently he is faster than a well regulated clock, which always keeps equable or equatorial time: and whilst he is in the second and fourth quadrants, he comes later to the meridian every day than he would do if he kept in the equator; and is therefore slower than the clock. But at the beginning of each quadrant, the sun and clock are equal.

And thus, if the sun moved equably in the ecliptic, he would be equal with the clock on four days of the year, which would have equal intervals of time between them. But as he moves faster at some times than at others (being eight days longer in the northern half of the ecliptic than in the southern) this will cause a second inequality; which, combined with the former, arising from the obliquity of the ecliptic to the equator, makes up that difference, which is shewn by the common equation tables to be between good clocks and true sundials.

The Description and Use of the Armillary Sphere.

Whoever has seen a common *armillary sphere*, (plate 4,

LECT. VIII. & IX. fig. 1.) and understands how to use it, must be sensible that the machine here referred to, is of a very different, and much more advantageous construction. And whoever has seen the curious glass sphere invented by Dr. LONG, or the figure of it in his Astronomy, must know that the furniture of the terrestial globe in this machine, the form of the pedestal, and the manner of turning either the earthly globe, or the circles which surround it, are all copied from the Doctor's glass sphere; and that the only difference is, a parcel of rings instead of a glass celestial globe; and all the additions are a moon within the sphere, and a semicircle upon the pedestal.

The armillary sphere. The exterior parts of this machine are a series of brass rings, which represent the principal circles of the heaven, viz. 1. The equinoctial *A A*, which is divided into 360 degrees (beginning at its intersection with the ecliptic in *Aries)* for shewing the sun's right ascension in degrees; and also in 24 hours, for shewing his right ascension in time. 2. The ecliptic *B B*, which is divided into 12 signs, and each sign into 30 degrees, and also into the months and days of the year; in such a manner, that the degree or point of the ecliptic in which the sun is, on any given day, stands over that day in the circle of months. 3. The tropic of *Cancer C C*, touching the ecliptic at the beginning of *Cancer* in *e*, and the tropic of *Capricorn D D*, touching the ecliptic at the beginning of *Capricorn* in *f*; each 23½ degrees from the equinoctial circle. 4. The arctic circle *E*, and the antarctic circle *F*, each 23½ degrees from its respective pole at *N* and *S*. 5. The equinoctial colure *G G*, passing through the north and south poles of the heaven at *N* and *S*, and through the equinoctial points *Aries*, and *Libra*, in the ecliptic. 6. The solstitial colure *H H*, passing through the poles of the heaven, and through the solstitial points *Cancer* and *Capricorn*, in the ecliptic. Each quarter of the former of these colures is divided into 90 degrees, from the equinoctial

to the poles of the world, for shewing the declination of the sun, moon, and stars; and each quarter of the latter, from the ecliptic at *e* and *f*, to its poles *b* and *d*, for shewing the latitudes of the stars. LECT. VIII. & X.

In the north pole of the ecliptic is a nut *b*, to which is fixed on one end of a quadrantal wire, and to the other end a small sun *Y*, which is carried round the ecliptic *B B*, by turning the nut: and in the south-pole of the ecliptic is a pin at *d*, on which is another quadrantal wire, with a small moon *Z* upon it, which may be moved round by hand: but there is a particular contrivance for causing the moon to move in an orbit which crosses the ecliptic at an angle of 5⅓ degrees, in two opposite points called the *moon's nodes;* and also for shifting these points backward in the ecliptic, as the *moon's nodes* shift in the heaven.

Within these circular rings is a small terrestrial globe *I*, fixed on an axis *K K*, which extends from the north and south poles of the globe at *n* and *s*, to those of the celestial sphere at *N* and *S*. On this axis is fixed the flat celestial meridian *L L*, which may be set directly over the meridian of any place on the globe, and then turned round with the globe, so as to keep over the same meridian upon it. This flat meridian is graduated the same way as the brass meridian of a common globe, and its use is much the same. To this globe is fitted the moveable horizon *M M*, so as to turn upon two strong wires proceeding from its east and west points to the globe, and entering the globe at opposite points of its equator, which is a moveable brass ring let into the globe in a groove all around its equator. The globe may be turned by hand within this ring, so as to place any given meridian upon it, directly under the celestial meridian *L L*. The horizon is divided into 360 degrees all round its outermost edge, within which are the points of the compass, for shewing the amplitude of the sun and moon, both in degrees and points. The celes-

[illegible] meridian [illegible] passes through two notches in the [illegible] as in a common [illegible] round, the hori-[illegible] At the south pole of [illegible] 24 hours, fixed to the rings, and [illegible] which goes round that circle, if [illegible]

The whole [illegible] supported on a pedestal N, and may be elevated or depressed upon the joint O, to any number of degrees from 0 to 90, by means of the arc P, which is fixed to the strong brass arm Q, and slides in the upright piece R, in which is a screw at r, to fix it at any proper elevation.

In the box T are two wheels (as in Dr. Long's sphere) and two pinions, whose axes come out at V and U; either of which may be turned by the small winch W. When the winch is put upon the axis V, and turned backward, the terrestrial globe, with its horizon and celestial meridian, keep at rest; and the whole sphere of circles turns round from east, by south, to west, carrying the sun Y and moon Z round the same way, and causing them to rise above and set below the horizon. But when the winch is put upon the axis U, and turned forward, the sphere with the sun and moon keep at rest; and the earth, with its horizon and meridian, turn round from west, by south, to east; and bring the same points of the horizon to the sun and moon, to which these bodies came when the earth kept at rest, and they were carried round: shewing that they rise and set in the same points of the horizon, and at the same times in the hour-circle, whether the motion be in the earth or in the heavens. If the earthly globe be turned, the hour-index goes round its hour-circle: but if the sphere be turned, the hour-circle goes round below the index.

And so, by this construction, the machine is equally

fitted to shew either the real motion of the earth, or the apparent motion of the heaven. LECT VIII.& IX.

To rectify the sphere for use, first slacken the screw *r* in the upright stem *R*, and taking hold of the arm *Q*, move it up or down until the given degree of latitude for any place be at the side of the stem *R*; and then the axis of the sphere will be properly elevated, so as to stand parallel to the axis of the world, if the machine be set north and south by a small compass: this done, count the latitude from the north-pole, upon the celestial meridian *L L*, down towards the north notch of the horizon, and set the horizon to that latitude; then, turn the nut *b* until the sun *Y* comes to the given day of the year in the ecliptic, and the sun will be at its proper place for that day: find the place of the moon's ascending node, and also the place of the moon, by an Ephemeris, and set them right accordingly: lastly, turn the winch *W*, until either the sun comes to the meridian *L L*, or until the meridian comes to the sun (according as you want the sphere or earth to move) and set the hour-index to the XII, marked noon, and the whole machine will be rectified.——Then turn the winch, and observe when the sun or moon rise and set in the horizon, and the hour-index will shew the times thereof for the given day.

As those who understand the use of the globes will be at no loss to work any other problems by this sphere, it is needless to enlarge any further upon it.[102]

Note 102. An admirable apparatus of this description has been constructed by Messrs. Jones of Holborn.

LECT. X.

LECTURE X.

THE PRINCIPLES AND ART OF DIALING.

Preliminaries.

A DIAL is a plane, upon which lines are described in such a manner, that the shadow of a wire, or of the upper edge of a plate stile, erected perpendicularly on the plane of the dial, may shew the true time of the day.

The edge of the plate by which the time of the day is found, is called the stile of the dial, which must be parallel to the earth's axis; and the line on which the said plate is erected, is called the substile.

The angle included between the substile and stile is called the elevation, or height of the stile.

Those dials whose planes are parallel to the plane of the horizon, are called horizontal dials; and those dials whose planes are perpendicular to the plane of the horizon, are called vertical, or erect dials.

Those erect dials, whose planes directly front the north or south, are called direct north or south dials; and all other erect dials are called decliners, because their planes are turned away from the north or south.

Those dials whose planes are neither parallel nor perpendicular to the plane of the horizon, are called inclining, or reclining dials, according as their planes make acute or obtuse angles with the horizon; and if their planes are also turned aside from facing the south or north, they are called declining-inclining, or declining-reclining dials.

The intersection of the plane of the dial, with that of the meridian, passing through the stile, is called the meridian of the dial, or the hour-line of XII.

Those meridians, whose planes pass through the stile, and make angles of 15, 30, 45, 60, 75, and 90 degrees

with the meridian plane of the place (which marks the hour-line of XII) are called hour-circles; and their intersections with the plane of the dial, are called hour-lines.

LECT. X.

In all declining dials, the substile makes an angle with the hour-line of XII; and this angle is called the distance of the substile from the meridian.

The declining plane's difference of longitude, is the angle formed at the intersection of the stile and plane of the dial, by two meridians; one of which passes through the hour-line of XII, and the other through the substile.

This much being premised concerning dials in general, we shall now proceed to explain the different methods of their construction.

The universal principle on which *dialing* depends.

If the whole earth *a P c p* were transparent and hollow, (plate 40, fig. 2.) like a sphere of glass, and had its equator divided into 24 equal parts by so many meridian semicircles, *a, b, c, d, e, f, g,* &c. one of which is the geographical meridian of any given place, as London, (which is supposed to be at the point *a*;) and if the hours of XII were marked at the equator, both upon that meridian and the opposite one, and all the rest of the hours in order on the rest of the meridians, those meridians would be the hour-circles of London: then, if the sphere had an opaque axis, as *P E p*, terminating in the poles *P* and *p*, the shadow of the axis would fall upon every particular meridian and hour, when the sun came to the plane of the opposite meridian, and would consequently shew the time at London, and at all other places on the meridian of London.

Horizontal dial.

If this sphere was cut through the middle by a solid plane *A B C D*, in the rational horizon of London, one half of the axis *E P* would be above the plane, and the other half below it; and if straight lines were drawn from the center of the plane, to those points where its

circumference, cut by the hour-circles of the sphere, these lines would be the hour-lines of a horizontal dial for London: for the shadow of the axis would fall upon each particular hour-line of the dial, when it fell upon the like hour-circle of the sphere.

If the plane which cuts the sphere be upright, as *AFCG* (plate 4. fig. 3.) touching the given place London at *F*, and directly facing the meridian of London, it will then become the plane of an erect direct south dial: and if right lines be drawn from its center *E*, to those points of its circumference where the hour-circles of the sphere cut it, these will be the hour-lines of a vertical or direct south dial for London, to which the hours are to be set as in the figure (contrary to those on a horizontal dial) and the lower half *Ep* of the axis will cast a shadow on the hour of the day in this dial, at the same time that it would fall upon the like hour-circle of the sphere, if the dial-plane was not in the way.

Inclining and reclining dials. If the plane (still facing the meridian) be made to incline, or recline, by any given number of degrees, the hour-circles of the sphere will still cut the edge of the plane in those points to which the hour-lines must be drawn straight from the center; and the axis of the sphere will cast a shadow on these lines at the respective hours. *Declining dials.* The like will still hold, if the plane be made to decline by any given number of degrees from the meridian, towards the east or west: provided the declination be less than 90 degrees, or the reclination be less than the co-latitude of the place: and the axis of the sphere will be a gnomon, or stile, for the dial. But it cannot be a gnomon, when the declination is quite 90 degrees, nor when the inclination is equal to the co-latitude; because in these two cases, the axis has no elevation above the plane of the dial.

And thus it appears, that the plane of every dial represents the plane of some great circle upon the earth;

he gnomon the earth's axis, whether it be a small as in the above figures, or the edge of a thin plate, the common horizontal dials. LECT. X.

e whole earth, as to its bulk, is but a point, if com-l to its distance from the sun: and therefore, if a sphere of glass be placed upon any part of the 's surface, so that its axis be parallel to the axis of arth, and the sphere have such lines upon it, and planes within it, as above described; it will shew ours of the day as truly as if it were placed at the 's center, and the shell of the earth were as trans-it as glass.

t because it is impossible to have a hollow sphere ss perfectly true, blown round a solid plane; or if , we could not get at the plane within the glass to in any given position; we make use of a wire-e to explain the principles of dialing, by joining micircles together at the poles, and putting a thin late of brass within it.

Dialing by the common terrestrial globe

ommon globe,[103] of 12 inches diameter, has generally eridian semicircles drawn upon it. If such a globe evated to the latitude of any given place, and d about until any one of these meridians cuts the on in the north point, where the hour of XII is sup-l to be marked, the rest of the meridians will cut orizon at the respective distances of all the other from XII. Then, if these points of distance be ed on the horizon, and the globe be taken out of orizon, and a flat board or plate be put into its , even with the surface of the horizon; and if ht lines be drawn from the center of the board, to points of distance on the horizon which were cut e 24 meridian semicircles, these lines will be the lines of a horizontal dial for that latitude, the edge

103. These constructions, by means of the globe, must be con-l rather as illustrations of the theory of dialing, than as ls which can be employed with practical advantage.

LECT. X. of whose gnomon must be in the very same situation that the axis of the globe was, before it was taken out of the horizon: that is, the gnomon must make an angle with the plane of the dial, equal to the latitude of the place for which the dial is made.

If the pole of the globe be elevated to the co-latitude[104] of the given place, and any meridian be brought to the north point of the horizon, the rest of the meridians will cut the horizon in the respective distances of all the hours from XII, for a direct south dial, [105] whose gnomon must make an angle with the plane of the dial, equal to the co-latitude of the place; and the hours must be set the contrary way on this dial, to what they are on the horizontal.

But if your globe have more than 24 meridian semicircles upon it, you must take the following method for making *horizontal* and *south dials*.

To construct a *horizontal dial.* Elevate the pole to the latitude of your place, and turn the globe until any particular meridian (suppose the first) comes to the north point of the horizon, and the opposite meridian will cut the horizon in the south. Then, set the hour-index to the uppermost XII on its circle; which done, turn the globe westward until 15 degrees of the eqrator pass under the brazen meridian, and then the hour-index will be at I, (for the sun moves 15 degrees every hour) and the first meridian will cut the horizon in the number of degrees from the north point, that I is distant from XII. Turn on, until other 15 degrees of the equator pass under the brazen meridian, and the hour-index will then be at II, and the first meridian will cut the horizon in the number of de-

Note 104. If the latitude be subtracted from 90 degrees, the remainder is called the co-latitude, or complement of the latitude.—*Note by the Author.*

Note 105. For if the *plane of the horizon* to the globe be placed in a vertical position, and directly facing the south, the axis of the globe will be parallel to the axis of the earth.

Pl. XII

Fig. 1.

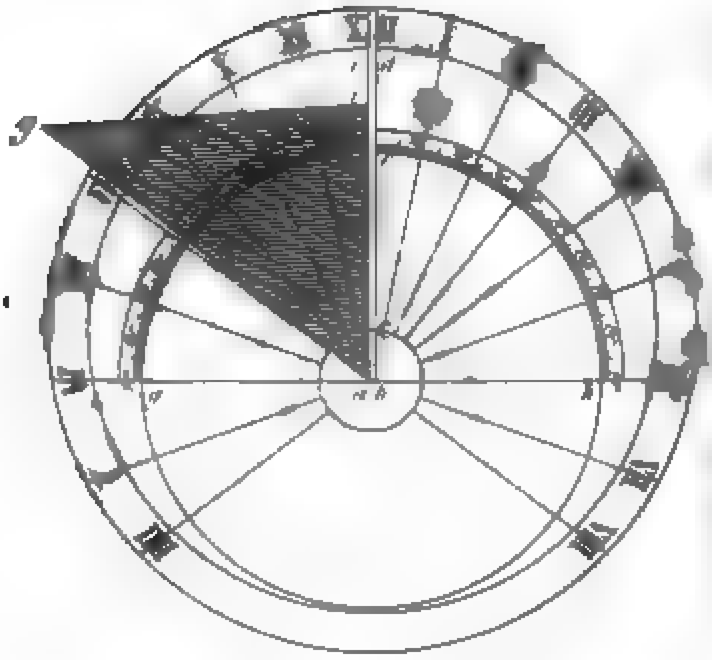


Fig. 2.

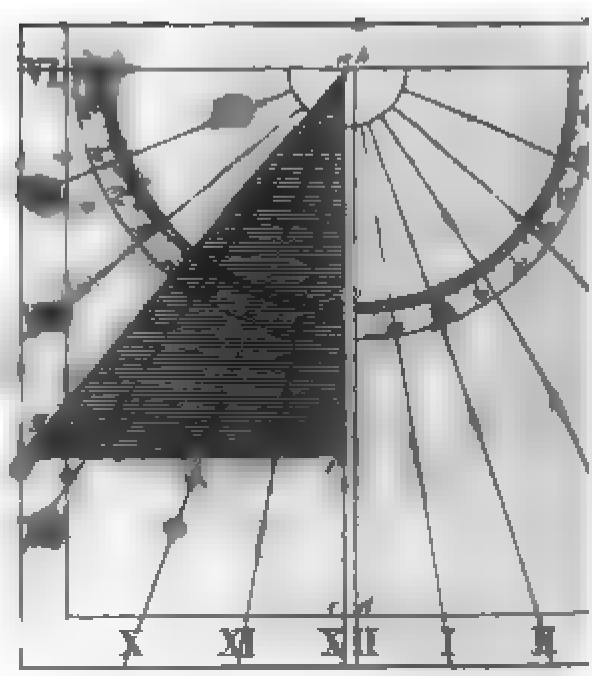


Fig. 3

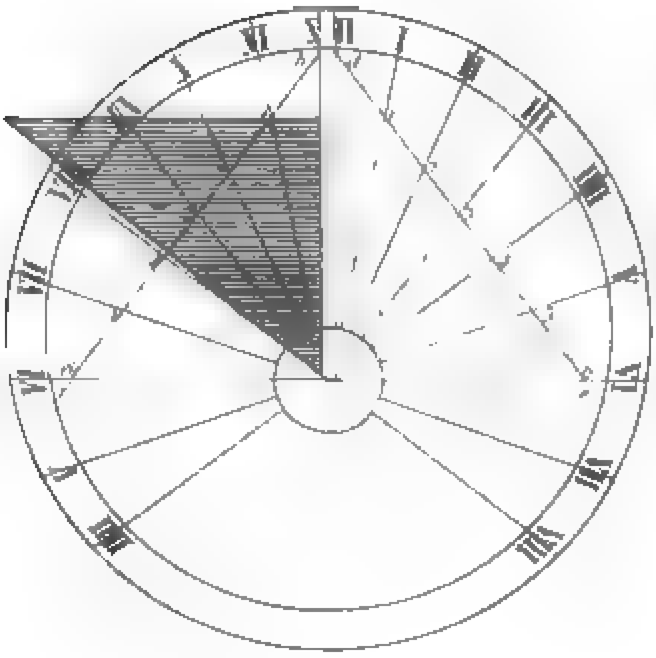
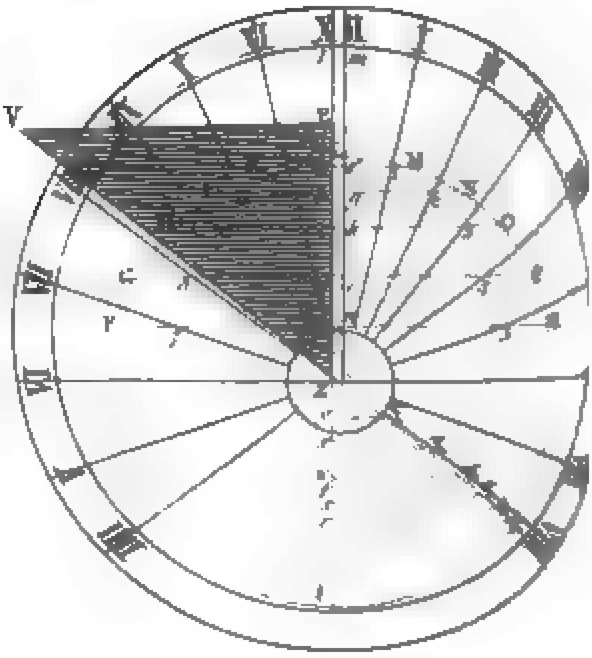


Fig. 4



J. Shury Sculp.

grees that II is distant from XII: and so, by making 15 degrees of the equator pass under the brazen meridian for every hour, the first meridian of the globe will cut the horizon in the distances of all the hours from XII to VI, which is just 90 degrees; and then you need go no farther, for the distances of XI, X, IX, VIII, VII, and VI, in the forenoon, are the same from XII, as the distances of I, II, III, IV, V, and VI, in the afternoon: and these hour-lines continued through the center, will give the opposite hour-lines on the other half of the dial: but no more of these lines need be drawn, than what answer to the sun's continuance above the horizon of your place on the longest day, which may be easily found by the 26th problem of the foregoing Lecture. LECT. X.

Thus, to make a horizontal dial for the latitude of London, which is $51\frac{1}{2}$ degrees north, elevate the north pole of the globe $51\frac{1}{2}$ degrees above the north point of the horizon, and then turn the globe, until the first meridian (which is that of London on the English terrestrial globe) cuts the north point of the horizon, and set the hour-index to XII at noon.

Then, turning the globe westward until the index points successively to I, II, III, IV, V, and VI, in the afternoon; or until 15, 30, 45, 60, 75, and 90 degrees of the equator pass under the brazen meridian, you will find that the first meridian of the globe cuts the horizon in the following numbers of degrees from the north towards the east, viz. $11\frac{2}{3}$, $24\frac{1}{4}$, $38\frac{1}{12}$, $53\frac{1}{3}$, $71\frac{1}{12}$, and 90; which are the respective distances of the above hours from XII upon the plane of the horizon.

To transfer these, and the rest of the hours, to a horizontal plane, draw the parallel right lines *a c* and *b d* upon that plane, as far from each other as is equal to the intended thickness of the gnomon or stile of the dial, and the space included between them will be the meridian or twelve o'clock line on the dial. Cross this Plate V. fig. 1.

meridian at right angles with the six o'clock line $g\,h$, and setting one foot of your compasses in the intersection a, as a center, describe the quadrant $g\,e$ with any convenient radius or opening of the compasses: then, setting one foot in the intersection b, as a center, with the same radius describe the quadrant $f\,h$, and divide each quadrant into 90 equal parts or degrees, as in the figure.

Because the hour-lines are less distant from each other about noon than in any other part of the dial, it is best to have the centers of these quadrants at a little distance from the center of the dial-plane, on the side opposite to XII, in order to enlarge the hour-distances thereabout under the same angles on the plane. Thus, the center of the plane is at C, but the centers of the quadrants are at a and b.*

Lay a ruler over the point b (and keeping it there for the center of all the afternoon hours in the quadrant $f\,h$) draw the hour-line of I through 11[illegible] degrees in the quadrant; the hour-line of II through 24[illegible] degrees; of III through 38[illegible] degrees; IV through 53[illegible], and V through 71[illegible]: and because the sun rises about four in the morning on the longest days at London, continue the hour-lines of IV and V in the afternoon through the center b to the opposite side of the dial.—This done, lay the ruler to the center a of the quadrant $e\,g$, and through the like divisions or degrees of that quadrant, viz. 11[illegible], 24[illegible], 38[illegible], 53[illegible], and 71[illegible], draw the forenoon

* Note. The enlarging the distance of the hour-lines, were they laid down from the center of the dial, would be no advantage, but would render the [illegible]. The center of the dial, which corresponds to the center of the globe, is at the intersection of the stile with the plane of the dial. But, since it is necessary to have the gnomon of some physical thickness, the edges of the gnomon become in fact the stile, and the shadow is cast by different edges in the morning and afternoon. The center of the dial therefore, which is the intersection of the stile, or edge casting the shadow with the plane of the dial, is alternately represented by a and b.

hour-lines of XI, X, IX, VIII, and VII; and because the sun sets not before eight in the evening on the longest days, continue the hour-lines of VII and VIII in the forenoon, through the center *a*, to VII and VIII in the afternoon; and all the hour-lines will be finished on this dial; to which the hours may be set, as in the figure. LECT. X.

Lastly, through 51½ degrees of either quadrant, and from its center, draw the right line *a g* for the hypothenuse or axis of the gnomon *a g i;* and from *g* let fall the perpendicular *g i*, upon the meridian line *a i*, and there will be a triangle made, whose sides are *a g*, *g i*, and *i a*. If a plate similar to this triangle be made as thick as the distance between the lines *a c* and *b d*, and set upright between them, touching at *a* and *b*, its hypothenuse *a g* will be parallel to the axis of the world, when the dial is truly set; and will cast a shadow on the hour of the day.

N. B. The trouble of dividing the two quadrants[107] may be saved, if you have a scale with a line of chords upon it, such as that on the right hand of the plate: for if you extend the compasses from 0 to 60 degrees of the line of chords, and with that extent, as a radius, describe the two quadrants upon their respective centers, the above distances may be taken with the compasses upon the line, and set off upon the quadrants.

To make an erect direct south dial. Elevate the pole to the co-latitude of your place, and proceed in all respects as above taught for the horizontal dial, from VI in the morning to VI in the afternoon, only the hours must be reversed, as in the figure; and the hypothenuse *a g*, of the gnomon *a g f*, must make an angle with the dial- To construct an *erect south dial.*

Note 107. The trouble of dividing the *two* quadrants is obviously unnecessary. It is sufficient to divide one, as *f h;* and, taking the distances from *f* to the points where the hour-lines of I, II, III, &c. intersect the quadrant *f h* in the compasses, to set them off from *e* on the quadrant *e g:* the lines drawn from the center *a*, to the points thus found, will be the forenoon hour lines, XI, X, IX, &c.

LECT. X.

plane equal to the co-latitude of the place. As the sun can shine no longer on this dial, than from six in the morning until six in the evening, there is no occasion for having any more than twelve hours upon it.

To construct an *erect declining dial.*

To make an erect dial, declining from the south towards the east or west. Elevate the pole to the latitude of your place, and screw the quadrant of altitude to the zenith. Then, if your dial declines towards the east (which we shall suppose it to do at present) count in the horizon the degrees of declination, from the east point towards the north, and bring the lower end of the quadrant to that degree of declination at which the reckoning ends. This done, bring any particular meridian of your globe (as suppose the first meridian) directly under the graduated edge of the upper part of the brazen meridian, and set the hour-index to XII at noon. Then, keeping the quadrant of altitude at the degree of declination in the horizon, turn the globe eastward on its axis, and observe the degrees cut by the first meridian in the quadrant of altitude (counted from the zenith) as the hour-index comes to XI, X, IX, &c. in the forenoon, or as 15, 30, 45, &c. degrees of the equator pass under the brazen meridian at these hours respectively; and the degrees then cut in the quadrant by the first meridian, are the respective distances of the forenoon hours from XII on the plane of the dial.—Then, for the afternoon hours, turn the quadrant of altitude round the zenith until it comes to the degree in the horizon opposite to that where it was placed before; namely, as far from the west point of the horizon towards the south, as it was set at first from the east point towards the north; and turn the globe westward on its axis, until the first meridian comes to the brazen meridian again, and the hour-index to XII: then, continue to turn the globe westward, and as the index points to the afternoon hours, I, II, III, &c. or as 15, 30, 45, &c. degrees of the equator pass under the brazen meridian, the first meridian will cut the

quadrant of altitude in the respective number of degrees from the zenith, that each of these hours is from XII on the dial.—And note, that when the first meridian goes off the quadrant at the horizon, in the forenoon, the hour-index shews the time when the sun will come upon this dial; and when it goes off the quadrant in the afternoon, the index will point to the time when the sun goes off the dial.

Having thus found all the hour-distances from XII, lay them down upon your dial-plate, either by dividing a semicircle into two quadrants of 90 degrees each (beginning at the hour-line of XII) or by the line of chords, as above directed.

In all declining dials, the line on which the stile or gnomon stands (commonly called the *substile-line*) makes an angle with the twelve o'clock line, and falls among the forenoon hour-lines, if the dial declines towards the east; and among the afternoon hour-lines, when the dial declines towards the west; that is, to the left hand from the twelve o'clock line in the former case, and to the right hand from it in the latter.

To find the distance of the substile from the twelve o'clock line; if your dial declines from the south towards the east, count the degrees of that declination in the horizon from the east point towards the north, and bring the lower end of the quadrant of altitude to that degree of declination where the reckoning ends: then, turn the globe until the first meridian cuts the horizon in the like number of degrees, counting from the south point towards the east; and the quadrant and first meridian will then cross each other at right angles, and the number of degrees of the quadrant, which are intercepted between the first meridian and the zenith, is equal to the distance of the substile line from the twelve o'clock line; and the number of degrees of the first meridian, which are intercepted between the quadrant and

LECT. X. the north pole, is equal to the elevation of the stile above the plane of the dial.

If the dial declines westward from the south, count that declination from the east point of the horizon towards the south, and bring the quadrant of altitude to the degree in the horizon at which the reckoning ends; both for finding the forenoon hours, and the distance of the substile from the meridian: and for the afternoon hours, bring the quadrant to the opposite degree in the horizon, namely, as far from the west towards the north, and then proceed in all respects as above.

Thus, we have finished our declining dial; and in so doing, we make four dials, viz.

1. A north dial, declining eastward by the same number of degrees. 2. A north dial, declining the same number west. 3. A south dial, declining east. And, 4. a south dial declining west. Only, placing the proper number of hours, and the stile or gnomon respectively, upon each plane. For (as above-mentioned) in the south-west plane, the substilar-line falls among the afternoon hours; and in the south-east, of the same declination among the forenoon hours, at equal distances from XII. And so, all the morning hours on the west decliner will be, like the afternoon hours, on the east decliner: the south-east decliner will produce the north-west decliner: and the south-west decliner, the north-east decliner, by only extending the hour-lines, stile and substile, quite through the center: the axis of the stile (or edge that casts the shadow on the hour of the day) being in all dials whatever parallel to the axis of the world, and consequently pointing towards the north pole of the heaven in north latitudes, and towards the south pole, in south latitudes.[108] *See more of this in the following lecture.*

Note 108. This is evident from the consideration that a plane will be intersected by the meridians of a sphere in the same points, in each of the four above mentioned positions.

LECT. X.

An easy method for constructing of dials.

But because every one who would like to make a dial, may perhaps not be provided with a globe to assist him, and may probably not understand the method of doing it by logarithmic calculation; we shall shew how to perform it by the plain dialing lines, or scale of latitudes and hours; such as those in plate V, or at the top of plate VI, and which may be had on scales commonly sold by mathematical instrument makers.

This is the easiest of all mechanical methods, and by much the best, when the lines are truly divided: not only the half hours and quarters may be laid down by all of them, but every fifth minute by most, and every single minute by those where the line of hours is a foot in length.

Having drawn your meridian line *a b*, *c d*, (fig. 3.) on the plane intended for a horizontal dial, and crossed it at right angles by the six o'clock line *f e* (as in fig. 1.) take the latitude of your place with the compasses, in the scale of latitudes, and set that extent from *c* to *e*, and from *a* to *f*, on the six o'clock line: then, taking the whole six hours between the points of the compasses in the scale of hours, with that extent set one foot in the point *c*, and let the other foot fall where it will upon the meridian line *c d*, as at *d*. Do the same from *f* to *b*, and draw the right line *e d* and *f b*, each of which will be equal in length to the whole scale of hours. This done, setting one foot of the compasses in the beginning of the scale at XII, and extending the other to each hour on the scale, lay off those extents from *d* to *e* for the afternoon hours, and from *b* to *f* for those of the forenoon: this will divide the lines *d e* and *b f* in the same manner as the hour-scale is divided, at 1, 2, 3, 4, 5 and 6; on which the quarters may be also laid down, if required. Then, laying a ruler on the point *c*, draw the first five hours in the afternoon, from that point, through the dots at the numeral figures 1, 2, 3, 4, 5, on the line *d e*; and continue the lines of IV and

LECT. X. V through the center c to the other side of the dial, for the like hours of the morning: which done, lay the ruler on the point a, and draw the last five hours in the forenoon through the dots 5, 4, 3, 2, 1, on the line fb; continuing the hour-lines of VII and VIII through the center a to the other side of the dial, for the like hours of the evening; and set the hours to their respective lines as in the figure. Lastly, make the gnomon the same way as taught above for the horizontal dial, and the whole will be finished.

To make an erect south dial, take the co-latitude of your place from the scale of latitudes, and then proceed in all respects for the hour-lines, as in the horizontal dial; only reversing the hours, as in Fig. 2: and making the angle of the stile's height equal to the co-latitude.

I have drawn out a set of dialing lines upon the top of the sixth plate, large enough for making a dial of nine inches diameter, or more inches if required; and have drawn them tolerably exact for common practice, to every quarter of an hour. This scale may be cut off from the plate, and pasted on wood, or upon the inside of one of the boards of this book; and then it will be somewhat more exact than it is on the plate; for being rightly divided upon the copper plate, and printed off on wet paper; it shrinks as the paper dries: but when it is wetted again, it stretches to the same size as when newly printed; and if pasted on while wet, it will remain of that size afterward.

But lest the young dialist should have neither globe nor wooden scale and should tear or otherwise spoil the paper one in pasting, we shall now shew how him he may make a dial without any of these helps. Only, if he has not a line of chords, he must divide a quadrant into 90 equal parts or degrees for taking the proper angle of the stile's elevation, which is easily done.[109]

Note 109. The instsument called the protractor will be found equally convenient.

With any opening of the compasses, as *Z L*, (plate 5, fig. 4.) desribe the two semicircles *L F k* and *L Q k*, upon the centers *Z* and *z*, where the six o'clock line crosses the double meridian line, and divide each semicircle into 12 equal parts, beginning at *L* (though, strictly speaking, only the quadrants from *L* to the six o'clock line need be divided:) then connect the divisions which are equidistant from *L*, by the parallel lines *K M*, *I N*, *H O*, *G P*, and *F Q*. Draw *V Z* for the hypothenuse of the stile, making the angle *V Z E* equal to the latitude of your place; and contiuue the line *V Z* to *R*. Draw the line *R r* parallel to the six o'clock line, and set off the distance *a K* from *Z* to *Y*, the distance *b I* from *Z* to *X*, *c H* from *Z* to *W*, *d G* from *Z* to *T*, and *e F* from *Z* to *S*. Then draw the lines *S s*, *T t*, *W w*, *X x*, and *Y y*, each parallel to *R r*. Set off the distance *y Y* from *a* to 11, and from *f* to 1; the distance *x X* from *b* to 10, and from *g* to 2; *w W* from *c* to 9, and from *h* to 3; *t T* from *d* to 8, and from *i* to 4; *s S* from *e* to 7, and from *n* to 5. Then laying a ruler to the center *Z*, draw the forenoon hour-lines through the points 11, 10, 9, 8, 7; and laying it to the center *z*, draw the afternoon lines through the points 1, 2, 3, 4, 5; continuing the forenoon lines of VII and VIII through the center *Z*, to the opposite side of the dial, for the like afternoon hours; and the afternoon lines IIII and V through the center *z*, to the opposite side, for the like morning hours. Set the hours to these lines as in the figure, and then erect the stile or gnomon, and the horizontal dial will be finished.

Horizontal dial.

South dial.

To construct a south dial, draw the line *V Z*, making an angle with the meridian *Z L* equal to the co-latitude of your place; and proceed in all respects as in the above horizontal dial for the same latitude, reversing the hours as in Fig. 2, and making the elevation of the gnomon equal to the co-latitude.

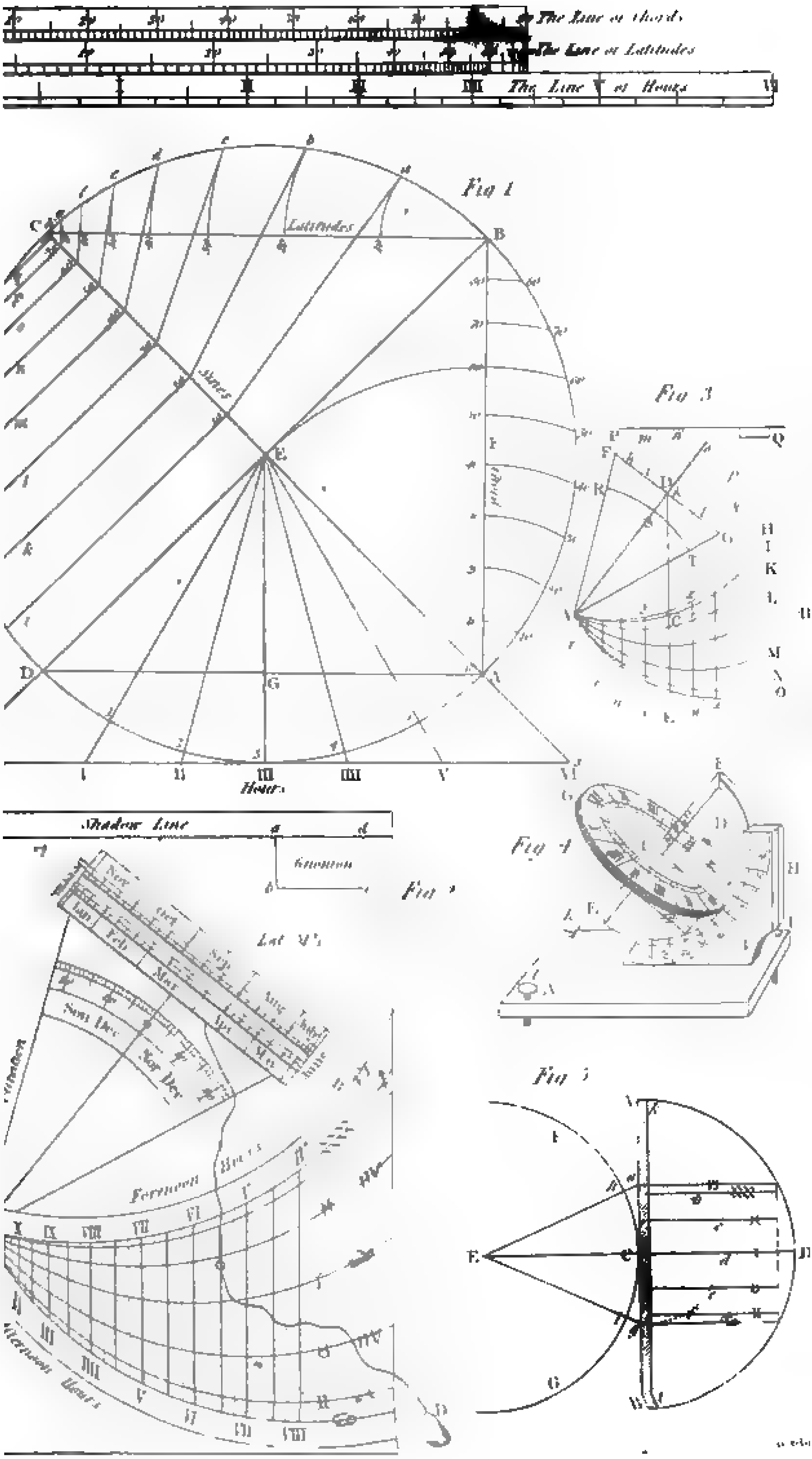
[illegible] to explain the [illegible] drawing lines, and some [illegible]

[illegible] compasses, as $E A$, (fig. 1. pl. [illegible] length of the scale, describe [illegible] at right angles by the [illegible] Divide the quadrant $A B$ [illegible] 10; so shall [illegible] equal parts or degrees. [illegible] this quadrant, [illegible] compasses in the point [illegible] of the quadrant, [illegible] $A F B$ by [illegible] and this will be a line of [illegible] parts; which, if transferred [illegible] quadrant, will divide it equally. [illegible] the figure, that the distance from A [illegible] is just equal to [illegible] that line is [illegible] of which A is [illegible] through the center E of the [illegible]

[illegible] number of degrees [illegible] first open the compasses [illegible] degrees upon [illegible] that extent, as [illegible] will be exactly of the same size [illegible] the line was divided: [illegible] compasses in the beginning [illegible] as at A, and extend the other to the number of degrees you want upon the line, which extent, applied to the circle, will include the like number of degrees upon it.

Divide the quadrant $C D$ into 90 equal parts, and from each point of division draw right lines, as i, k, l, &c. to the line $C E$; all perpendicular to that line, and parallel to $D E$, which will divide $E C$ into a line of

PLATE VI


The Line of Chords
The Line of Latitudes
The Line of Hours
Fig 1
Latitudes
Sines
Hours
Fig 3
Fig 4
Fig 2
Shadow Line
Gnomon
Lat 51½
Forenoon Hours
Afternoon Hours
Fig 5

ines; and although these are seldom put among the ialing lines on a scale, yet they assist in drawing the ne of latitudes. For, if a ruler be laid upon the point), and over each division in the line of sines, it will ivide the quadrant *CB* into 90 unequal parts, as *Ba*, *b*, &c. shewn by the right lines 10 *a*, 20 *b*, 30 *c*, &c. rawn along the edge of the ruler. If the right line 3 *C* be drawn, subtending this quadrant, and the nearst distances *B a*, *B b*, *B c*, &c. be taken in the comasses from *B*, and set upon this line in the same maner as directed for the line of chords, it will make a line f latitudes *B C*, equal in length to the line of chords 1 *B*, and of an equal number of divisions, but very unqual as to their lengths.

Draw the right line *D G A*, subtending the quadrant) *A*; and parallel to it, draw the right line *r s*, touching he quadrant *D A* at the numeral figure 3. Divide this uadrant into six equal parts, as 1, 2, 3, &c. and hrough these points of division draw right lines from he center *E* to the line *r s*, which will divide it at the oints where the six hours are to be placed, as in the igure. If every sixth part of the quadrant be subdiided into four equal parts, right lines drawn from the enter through these points of division, and continued to he line *r s*, will divide each hour upon it into quarters.

A dial on a card.

In fig. 2, plate 6, we have the representation of a porable dial, which may be easily drawn on a card, and arried in a pocket-book. The lines *a d*, *a b* and *b c* of he gnomon must be cut quite through the card; and s the end *a b* of the gnomon is raised occasionally bove the plane of the dial, it turns upon the uncut line *d* as on a hinge. The line dotted *A B* must be slit uite through the card, and the thread must be put hrough the slit, and have a knot tied behind, to keep it from being easily drawn out. On the other end of this thread is a small plummet, and on the middle of it a small bead for shewing the hour of the day.

LECT. X. To rectify this dial, set the thread in the slit right against the day of the month, and stretch the thread from the day of the month over the angular point where the curve lines meet at XII; then shift the bead to that point on the thread, and the dial will be rectified.

To find the hour of the day, raise the gnomon (no matter how much or how little) and hold the edge of the dial next the gnomon towards the sun, so that the uppermost edge of the shadow of the gnomon may just cover the *shadow-line;* and the bead then playing freely on the face of the dial, by the weight of the plummet, will shew the time of the day among the hour-lines, as it is forenoon or afternoon.

To find the time of sun-rising and setting, move the thread among the hour-lines, until it either covers some one of them, or lies parallel betwixt any two; and then it will cut the time of sun-rising among the forenoon hours, and of sun-setting among the afternoon hours, on that day of the year for which the thread is set in the scale of months.

To find the sun's declination, stretch the thread from the day of the month over the angular point at XII, and it will cut the sun's declination, as it is north or south, for that day, in the arched scale of north and south declination.

To find on what days the sun enters the signs: when the bead, as above rectified, moves along any of the curve lines which have the signs of the zodiac marked upon them, the sun enters those signs on the days pointed out by the thread in the scale of months.

The construction of this dial is very easy, especially if the reader compares it all along with Fig. 3. as he reads the following explanation of that figure.

Draw the occult line *A B* (fig. 3, plate 6.) parallel to the top of the card, and cross it at right angles with the six o'clock line *E C D;* then upon *C*, as a center, with

e radius *C A*, describe the semicircle *A E L*, and vide it into 12 equal parts (beginning at *A*) as *A r*, *s*, &c. and from these points of division, draw the our-lines *r*, *s*, *t*, *u*, *v*, *E*, *w*, and *x*, all parallel to the x o'clock line *E C*. If each part of the semicircle be bdivided into four equal parts, they will give the half-our lines and quarters, as in fig. 2. Draw the right ie *A S D o*, making the angle *S A B* equal to the titude of your place. Upon the center *A* describe the ch *R S T*, and set off upon it the arcs *S R* and *S T* ch equal to 23½ degrees, for the sun's greatest decli-ution; and divide them into 23½ equal parts, as in fig. 2. hrough the intersection *D* of the lines *E C D* and *D o*, draw the right line *F D G* at right angles to *D o*. Lay a ruler to the points *A* and *R*, and draw e line *A R F* through 23½ degrees of south declination the arc *S R*; and then laying the ruler to the points and *T*, draw the line *A T G* through 23½ degrees of orth declination in the arc *S T*: so shall the lines *R F* and *A T G* cut the line *F D G* in the proper ngth for the scale of months. Upon the center *D*, ith the radius *D F*, describe the semicircle *F o G*; id divide it into six equal parts, *F m*, *m n*, *n o*, &c. id from these points of division draw the right lines *h*, *n i*, *p k*, and *q l*, each parallel to *o D*. Then setting ie foot of the compasses in the point *F*, extend the her to *A*, and describe the arc *A z H* for the tropic ♑: with the same extent, setting one foot in *G*, de-ribe the arc *A E O* for the tropic of ♋. Next set-ig one foot in the point *h*, and extending the other to , describe the arc *A C I* for the beginnings of the gns ♒ and ♐; and with the same extent, setting one ot in the point *l*, describe the arc *A N* for the begin-ngs of the signs ♊ and ♌. Set one foot in the point and having extended the other to *A*, describe the arc *K* for the beginnings of the signs ♓ and ♏; and with e same extent, set one foot in *k*, and describe the arc

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A M for the beginnings of the signs ♉ and ♍. Then, setting one foot in the point *D*, and extending the other to *A*, describe the curve *A L* for the beginnings of ♈ and ♎; and the signs will be finished. This done, lay a ruler from the point *A* over the sun's declination in the arch *R S T*, (found by the following table) for every fifth day of the year: and where the ruler cuts the line *F D G*, make marks; and place the days of the months right against these marks, in the manner shewn by fig. 2. Lastly, draw the shadow line *P Q* parallel to the occult line *A B*; make the gnomon, and set the hours to their respective lines, as in fig. 2. and the dial will be finished.

An universal dial.

There are several kinds of dials, (fig. 4.) which are called *universal*, because they serve for all latitudes. Of these, the best one that I know, is *Mr. Pardie's*, which consists of three principal parts; the first whereof is called the *horizontal plane (A)*, because in the practice it must be parallel to the horizon. In this plane is fixed an upright pin, which enters into the edge of the second part *B D*, called the *meridional plane*; which is made of two pieces, the lowest whereof *(B)* is called the *quadrant*, because it contains a quarter of a circle, divided into 90 degrees; and it is only into this part, near *B*, that the pin enters. The other piece is a *semicircle (D)* adjusted to the quadrant, and turning in it by a groove, for raising or depressing the diameter *(E F)* of the semicircle, which diameter is called the *axis* of the instrument. The third piece is a *circle (G)*, divided on both sides into 24 equal parts, which are the hours. This circle is put upon the meridional plane, so that the axis *(E F)* may be perpendicular to the circle; and the point *C* be the common center of the circle, semicircle, and quadrant. The straight edge of the semicircle is chamfered on both sides to a sharp edge, which passes through the center of the circle. On one side of the chamfered part, the first six months of the year are laid down, ac-

cording to the sun's declination for their respective days, and on the other side the last six months. And against the days on which the sun enters the signs, there are straight lines drawn upon the semicircle, with the characters of the signs marked upon them. There is a black line drawn along the middle of the upright edge of the quadrant, over which hangs a thread *(H)*, with its plummet *(i)* for levelling the instrument.

N. B. From the 23d of September to the 20th of March, the upper surface of the circle must touch both the center *C* of the semicircle, and the line of ♈ and ♎; and from the 20th of March to the 23d of September, the lower surface of the circle must touch that center and line.

To find the time of the day by this dial. Having set it on a level place in sun-shine, and adjusted it by the levelling screws *k* and *l*, until the plumb-line hangs over the black line upon the edge of the quadrant, and parallel to the said edge; move the semicircle in the quadrant, until the line of ♈ and ♎ (where the circle touches) comes to the latitude of your place in the quadrant: then, turn the whole meridional plane *B D*, with its circle *G*, upon the horizontal plane *A*, until the edge of the shadow of the circle falls precisely on the day of the month in the semicircle;[110] and then, the meridional

Note 110. Since the plane of the dial, when the instrument is rectified, is parallel to the equinoctial plane, and the declination of the sun may be considered to remain the same whilst he continues above the horizon, it follows, that the point where the shadow of the dial-plate falls upon the edge *E F* on any particular day, will not alter its position during that day. Now the angle formed by a line drawn from that point to any point in the edge of the dial-plate with the dial plate itself, is evidently equal to the declination of the sun on the given day. But the tangents of the sun's declinations to the radius of the dial-plate, are marked upon this edge with the corresponding day of the month. Consequently, the dial-plate being elevated to the proper angle above the horizontal plane; if the dial be placed north and south, the shadow of the edge of the dial-plate will fall on the day of

LECT. X. plane will be due north and south, the axis $E F$ will be parallel to the axis of the world, and will cast a shadow upon the true time of the day, among the hours on the circle.

N. B. As, when the instrument is thus rectified, the quadrant and semicircle are in the plane of the meridian, so the circle is then in the plane of the equinoctial. Therefore, as the sun is above the equinoctial in summer in northern latitudes, and below it in winter; the axis of the semicircle will cast a shadow on the hour of the day, on the upper surface of the circle, from the 20th of March to the 23d of September: and from the 23d of September, to the 20th of March, the hour of the day will be determined by the shadow of the semicircle, upon the lower surface of the circle. In the former case, the shadow of the circle falls upon the day of the month, on the lower part of the diameter of the semicircle; and in the latter case, on the upper part.

The method of laying down the months and signs upon the semicircle, is as follows. Draw the right line $A C B$, (fig. 5,) equal to the diameter of the semicircle $A D B$, and cross it in the middle at right angles with the line $E C D$, equal in length to $A D B$; then $E C$ will be the radius of the circle $F C G$, which is the same as that of the semicircle. Upon E, as a center, describe the circle $F C G$, on which set off the arcs $C h$ and $C i$, each equal to 23½ degrees, and divide them accordingly into that number, for the sun's declination. Then, laying the edge of a ruler over the center E, and also over the sun's declination for every[111] fifth day of each month (as in the card dial) mark the points on the diameter $A B$ of the semicircle from a to g, which are cut

the month: and *vice versa* if the dial-plate be turned, until the shadow of its edge falls upon the day of the month, then the dial will be set truly north and south.

Note 111. The intermediate days may be drawn in by hand, if the space be large enough to contain them.—*Note by the Author.*

by the ruler; and *there* place the days of the months accordingly, answering the sun's declination. This done, setting one foot of the compasses in *C*, and extending the other to *a* or *g*, describe the semicircle *a b c d e f g*; which divide into six equal parts, and through the points of division draw right lines, parallel to *C D*, for the beginning of the sines (of which one half are on one side of the semicircle, and the other half on the other side) and set the characters of the signs to their proper lines, as in the figure.

The following table shews the sun's place and declination, in degrees and minutes, at the noon of every day of the second year after leap-year; which is a mean between those of leap-year itself, and the first and third years after. It is useful for inscribing the months and their days on sun-dials; and also for finding the latitudes of places, according to the methods prescribed after the table.

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A Table shewing the sun's place and declination.

JANUARY.					FEBRUARY.				
DAYS.	Sun's Pl.		Sun's Dec.		DAYS.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	11 ♑	5	23 S	1	1	12 ♒	38	17 S	2
2	12	6	22	55	2	13	39	16	45
3	13	8	22	49	3	14	40	16	27
4	14	9	22	43	4	15	41	16	10
5	15	10	22	37	5	16	41	15	51
6	16	11	22	29	6	17	42	15	33
7	17	12	22	22	7	18	43	15	14
8	18	13	22	14	8	19	43	14	55
9	19	14	22	5	9	20	44	14	36
10	20	16	21	56	10	21	45	14	17
11	21	17	21	47	11	22	45	13	57
12	22	18	21	37	12	23	46	13	37
13	23	19	21	27	13	24	46	13	17
14	24	20	21	17	14	25	47	12	57
15	25	21	21	6	15	26	47	12	36
16	26	22	20	54	16	27	48	12	15
17	27	24	20	43	17	28	48	11	54
18	28	25	20	30	18	29	48	11	33
19	29	26	20	18	19	0 ♓	49	11	12
20	0 ♒	27	20	5	20	1	49	10	50
21	1	28	19	52	21	2	50	10	29
22	2	29	19	38	22	3	50	10	7
23	3	30	19	24	23	4	50	9	45
24	4	31	19	10	24	5	51	9	23
25	5	32	18	55	25	6	51	9	0
26	6	33	18	40	26	7	51	8	38
27	7	34	18	24	27	8	51	8	16
28	8	35	18	9	28	9	51	7	53
29	9	35	17	53					
30	10	36	17	36					
31	11	37	17	19					

In these Tables N signifies north declination, and S south.

LECT. X.

A Table shewing the sun's place and declination.

MARCH.					APRIL.			
Sun's Pl.		*Sun's Dec.*		DAYS.	*Sun's Pl.*		*Sun's Dec.*	
D.	M.	D.	M.		D.	M.	D.	M.
10 ♓	52	7 S	30	1	11 ♈	38	4 N	36
11	52	7	7	2	12	37	4	59
12	52	6	44	3	13	36	5	22
13	52	6	21	4	14	35	5	45
14	52	5	58	5	15	34	6	8
15	52	5	35	6	16	33	6	31
16	51	5	12	7	17	31	6	53
17	51	4	48	8	18	30	7	16
18	51	4	25	9	19	29	7	38
19	51	4	2	10	20	28	8	0
20	51	3	38	11	21	27	8	22
21	50	3	14	12	22	25	8	24
22	50	2	51	13	23	24	9	6
23	50	2	27	14	24	23	9	28
24	49	2	4	15	25	21	9	49
25	49	1	40	16	26	20	10	11
26	48	1	16	17	27	18	10	32
27	48	0	53	18	28	17	10	53
28	48	0	29	19	29	15	11	14
29	47	0	5	20	0 ♉	14	11	34
0 ♈	47	0 N	19	21	1	12	11	55
1	46	0	42	22	2	11	12	15
2	45	1	6	23	3	9	12	35
3	45	1	29	24	4	7	12	55
4	44	1	53	25	5	6	13	14
5	43	2	17	26	6	4	13	34
6	42	2	40	27	7	2	13	53
7	42	3	3	28	8	0	41	12
8	41	3	27	29	8	59	41	30
9	40	3	50	30	9	57	14	49
10	39	4	13					

LECT. X.

A Table shewing the sun's place and declination.

MAY.					JUNE.				
DAYS.	Sun's Pl.		Sun's Dec.		DAYS.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	10 ♉	55	15 N	7	1	10 ♊	44	22 N	5
2	11	53	15	25	2	11	41	22	13
3	12	51	15	43	3	12	39	22	21
4	13	49	16	0	4	13	36	22	28
5	14	47	16	18	5	14	34	22	35
6	15	45	16	35	6	15	31	22	41
7	16	43	16	51	7	16	28	22	47
8	17	41	17	8	8	17	26	22	53
9	18	39	17	24	9	18	23	22	58
10	19	36	17	40	10	19	20	23	3
11	20	34	17	55	11	20	18	23	7
12	21	32	18	10	12	21	15	23	11
13	22	30	18	25	13	22	12	23	15
14	23	28	18	40	14	23	9	23	18
15	24	25	18	54	15	24	7	23	20
16	25	23	19	8	16	25	4	23	22
17	26	21	19	22	17	26	1	23	24
18	27	19	19	35	18	26	58	23	26
19	28	16	19	48	19	27	56	23	27
20	29	14	20	1	20	28	53	23	28
21	0 ♊	11	20	13	21	29	50	23	28
22	1	9	20	25	22	0 ♋	47	23	28
23	2	7	20	37	23	1	45	23	28
24	3	4	20	48	24	2	42	23	27
25	4	2	20	59	25	3	39	23	26
26	4	59	21	10	26	4	36	23	24
27	5	57	21	20	27	5	33	23	21
28	6	54	21	30	28	6	31	23	19
29	7	52	21	39	29	7	28	23	16
30	8	49	21	49	30	8	25	23	12
31	9	47	21	57					

A Table shewing the sun's place and declination.

JULY.					AUGUST.			
Sun's Pl.		*Sun's Dec.*		DAYS.	*Sun's Pl.*		*Sun's Dec.*	
D.	M.	D.	M.		D.	M.	D.	M.
9 ♋	22	23 N	8	1	8 ♌	58	18 N	2
10	19	23	4	2	9	55	17	47
11	16	23	0	3	10	53	17	32
12	14	22	55	[illegible]	11	50	17	16
13	11	22	49	5	12	[illegible]	17	0
14	[illegible]	22	43	6	13	45	16	[illegible]
15	5	22	37	7	14	43	16	[illegible]
16	0	22	30	8	15	[illegible]	16	9
17	2	22	23	9	16	38	15	52
17	57	22	16	10	17	36	15	25
18	54	22	8	11	18	33	15	17
19	51	22	0	12	19	31	14	59
20	49	21	52	13	20	29	14	41
21	46	21	43	14	21	26	14	23
22	43	21	33	15	22	24	14	4
23	40	21	22	16	23	22	13	45
24	38	21	14	17	24	20	13	26
25	35	21	3	18	25	17	13	7
26	32	20	52	19	26	15	12	47
27	29	20	41	20	27	13	12	27
28	27	20	30	21	28	11	12	7
29	24	20	18	22	29	9	11	47
0 ♌	21	20	6	23	0 ♍	7	11	27
1	19	19	54	24	1	5	11	6
2	16	19	41	25	2	3	10	46
3	13	19	28	26	3	1	10	25
4	11	19	14	27	3	59	10	4
5	8	19	1	28	4	57	9	43
6	6	18	46	29	5	55	9	21
7	3	18	32	30	6	53	9	0
8	0	18	17	31	7	51	8	[illegible]

LECT. X.

A Table shewing the sun's place and declination.

SEPTEMBER					OCTOBER.				
DAYS.	Sun's Pl.		Sun's Dec.		DAYS.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	8 ♍	49	8 N	16	1	8 ♎	8	3 S	14
2	9	47	7	55	2	9	7	3	37
3	10	46	7	33	3	10	7	4	1
4	11	44	7	10	4	11	6	4	24
5	12	42	6	48	5	12	5	4	47
6	13	40	6	26	6	13	4	5	10
7	14	39	6	3	7	14	4	5	33
8	15	37	5	41	8	15	3	5	56
9	16	35	5	18	9	16	3	6	19
10	17	34	4	55	10	17	2	6	42
11	18	32	4	32	11	18	1	7	5
12	19	31	4	9	12	19	1	7	27
13	20	29	3	46	13	20	0	7	50
14	21	28	3	23	14	21	0	8	12
15	22	26	3	0	15	22	0	8	35
16	23	25	2	37	16	23	0	8	57
17	24	25	2	14	17	23	59	9	19
18	25	22	1	50	18	24	59	9	41
19	26	21	1	27	19	25	58	10	3
20	27	20	1	4	20	26	58	10	24
21	28	19	0	40	21	27	58	10	46
22	29	17	0	17	22	28	58	11	7
23	0 ♎	16	0 S	6	23	29	58	11	28
24	1	15	0	30	24	0 ♏	58	11	49
25	2	14	0	53	25	1	58	12	10
26	3	13	1	17	26	2	58	12	31
27	4	12	1	40	27	3	58	12	51
28	5	11	2	4	28	4	58	13	12
29	6	10	2	27	29	5	58	13	32
30	7	9	2	50	30	6	58	13	51
					31	7	58	14	11

A Table shewing the sun's place and declination.

NOVEMBER.					DECEMBER.				
DAYS.	Sun's Pl.		Sun's Dec.		DAYS.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	8 ♏	58	14 s	30	1	9 ♐	16	21 s	52
2	9	58	14	50	2	10	17	22	1
3	10	59	15	8	3	11	18	22	10
4	11	59	15	27	4	12	19	22	18
5	12	59	15	45	5	13	20	22	26
6	13	59	16	3	6	14	21	22	33
7	15	0	16	21	7	15	22	22	40
8	16	0	16	39	8	16	23	22	46
9	17	0	16	56	9	17	24	22	52
10	18	1	17	13	10	18	25	22	58
11	19	1	17	30	11	19	26	23	3
12	20	2	17	46	12	20	27	23	8
13	21	2	18	2	13	21	28	23	12
14	22	3	18	18	14	22	29	23	15
15	23	4	18	34	15	23	30	23	18
16	24	4	18	49	16	24	31	23	21
17	25	5	19	4	17	25	33	23	24
18	26	5	19	18	18	26	34	23	26
19	27	6	19	32	19	27	35	23	27
20	28	7	19	46	20	28	36	23	28
21	29	7	19	59	21	29	37	23	28
22	0 ♐	8	20	12	22	0 ♑	38	23	28
23	1	9	20	25	23	1	40	23	28
24	2	10	20	37	24	2	41	23	27
25	3	11	20	49	25	3	42	23	25
26	4	11	21	1	26	4	43	23	23
27	5	12	21	12	27	5	44	23	21
28	6	13	21	23	28	6	46	23	18
29	7	14	21	33	29	7	47	23	15
30	8	15	21	43	30	8	48	23	11
					31	9	49	23	6

LECT X.

To find the latitude of any place by observation.

The latitude of any place is equal to the elevation of the pole above the horizon of that place. Therefore it is plain, that if a star was fixed in the pole, there would be nothing required to find the latitude, but to take the altitude of that star with a good instrument. But although there is no star in the pole, yet the latitude may be found by taking the greatest and least altitude of any star that never sets: for if half the difference between these altitudes be added to the least altitude, or subtracted, from the greatest, the sum or remainder will be equal to the altitude of the pole at the place of observation.

But because the length of the night must be more than 12 hours, in order to have two such observations; the sun's meridian altitude and declination are generally made use of for finding the latitude, by means of its complement, which is equal to the elevation of the equinoctial above the horizon; and if this complement be subtracted from 90 degrees, the remainder will be the latitude; concerning which, I think, the following rules take in all the various cases.

1. If the sun has north declination, and is on the meridian, and to the south of your place, subtract the declination from the meridian altitude (taken by a good quadrant) and the remainder is the height of the equinoctial or complement of the latitude north.

EXAMPLE.

Suppose { The sun's meridian altitude	42°	20′	South
{ And his declination, subt.	10	15	North
Rem. the complement of the lat. . .	32	5	
Which subtract from	90	0	
And the remainder is the latitude . .	57	55	North

2. If the sun has south declination, and is southward of your place at noon, add the declination to the meridian altitude; the sum, if less than 90 degrees, is the complement of the latitude north: but if the sum exceeds 90 degrees, the latitude is south; and if 90 be taken from that sum, the remainder will be the latitude.

EXAMPLES.

The sun's meridian altitude	65°	10′	South
The sun's declination, add	15	30	South
Complement of the latitude. . . .	80	40	
Subtract from	90	0	
Remains the latitude	9	20	North.

The sun's meridian altitude . . .	80°	40′	South
The sun's declination, add	20	10	South
The sum is	100	50	
From which subtract.	90	0	
Remains the latitude	10	50	South.

3. If the sun has north declination, and is on the meridian north of your place, add the declination to the north meridian altitude; the sum if less than 90 degrees, is the complement of the latitude south: but if the sum is more than 90 degrees, subtract 90 from it, and the remainder is the latitude north.

EXAMPLES.

Sun's meridian altitude	60°	30′	North
Sun's declination, add	20	10	North
Complement of the latitude	80	40	
Subtract from	90	0	
Remains the latitude	9	20	South

LECT X.

Sun's meridian altitude	70°	20′	North
Sun's declination, add	23	20	North
The sum is	93	40	
From which subtract	90	0	
Remains the latitude	3	40	North.

4. If the sun has south declination, and is north of your place at noon, subtract the declination from the north meridian altitude, and the remainder is the complement of the latitude south.

EXAMPLE.

Sun's meridian altitude	50°	30′	North
Sun's declination, subtract . . .	20	10	South
Complement of the latitude	32	20	
Subtract this from	90	0	
And the remainder is the latitude .	57	40	South.

5. If the sun has no declination, and is south of your place at noon, the meridian altitude is the complement of the latitude north: but if the sun be then north of your place, his meridian altitude is the complement of the latitude south.

EXAMPLES.

Sun's meridian altitude	38°	30′	South
Subtract from	90	0	
Remains the latitude	51	30	North.

Sun's meridian altitude	38°	30′	North
Subtract from	90	0	
Remains the latitude	51	30	South.

If you observe the sun beneath the pole, subtract his declination from 90 degrees, and add the remainder to his altitude; and the sum is the latitude.

EXAMPLE.

Sun's declination	20°	30	
Subtract from	90	0	
Remains	69	30	add
Sun's altitude below the pole . . .	10	20	
The sum is the latitude . . . , . .	79	50	

Which is north or south, according as the sun's declination is north or south: for when the sun has south declination, he is never seen below the north pole; nor is he ever seen below the south pole, when his declination is north.

7. If the sun be in the zenith at noon, and at the same time has no declination, you are then under the equinoctial, and so have no latitude.

8. If the sun be in the zenith at noon, and has declination, the declination is equal to the latitude, north or south. These two cases are so plain, that they require no examples.[112]

Note 112. The method here detailed is subject to any error which may exist in the tables of the declination of the sun. A series of altitudes of the pole-star observed constantly on the meridian both above and below the pole appears to offer the method least liable to error. Ferguson objects to this method, because one of the observations must be made in the day time, but it is well known that the stars which are above the horizon, are visible at all times, through a telescope, even of moderate power. Several corrections are necessary in each of these methods, if accuracy is required, as for refraction, &c.

LECTURE XI.

OF DIALING.

HAVING shewn in the preceding Lecture how to make sun-dials by the assistance of a good globe, or of a dialing scale, we shall now proceed to the method of constructing dials arithmetically: which will be more agreeable to those who have learned the elements of trigonometry, because globes and scales can never be so accurate as the logarithms, in finding the angular distances of the hours. Yet, as a globe may be found exact enough for some other requisites in dialing, we shall take it in occasionally.

The construction of sun-dials on all planes whatever, may be included in one general rule: intelligible, if that of a horizontal dial for any given latitude be well understood. For there is no plane, however obliquely situated with respect to any given place, but what is parallel to the horizon of some other place; and therefore, if we can find that other place by a problem on the terrestrial globe, or by a trigonometrical calculation, and construct a horizontal dial for it; that dial, applied to the plane where it is to serve, will be a true dial for that place.—Thus, an erect direct south dial in 51½ degrees north latitude, would be a horizontal dial on the same meridian, 90 degrees southward of 51½ degrees north latitude: which falls in with 38½ degrees of south latitude. But if the upright plane declines from facing the south at the given place, it would still be a horizontal plane 90 degrees from that place; but for a different longitude: which would alter the reckoning of the hours accordingly.

CASE I.

1. Let us suppose that an upright plane at London declines 36 degrees westward from facing the south; and that it is required to find a place on the globe, to whose horizon the said plane is parallel; and also the difference of longitude between London and that place.

Rectify the globe to the latitude of London, and bring London to the zenith under the brass meridian, then that point of the globe which lies in the horizon at the given degree of declination (counted westward from the south point of the horizon) is the place at which the above-mentioned plane would be horizontal.—Now, to find the latitude and longitude of that place, keep your eye upon the place, and turn the globe eastward, until it comes under the graduated edge of the brass meridian; then, the degree of the brass meridian that stands directly over the place, is its latitude; and the number of degrees in the equator, which are intercepted between the meridian of Londen and the brass meridian, is the place's difference of longitude.

Thus, as the latitude of London is 51½ degrees north, and the declination of the place is 36 degrees west; I elevate the north pole 51½ degrees above the horizon, and turn the globe until London comes to the zenith, or under the graduated edge of the meridian: then, I count 36 degrees on the horizon westward from the south point, and make a mark on that place of the globe over which the reckoning ends, and bringing the mark under the graduated edge of the brass meridian, I find it to be under 30½ degrees in south latitude: keeping it there, I count in the equator the number of degrees between the meridian of London and the brazen meridian (which now becomes the meridian of the required place) and find it to be 42⅛. Therefore an upright plane at London, declining 36 degrees westward from the south,

LECT. XI.

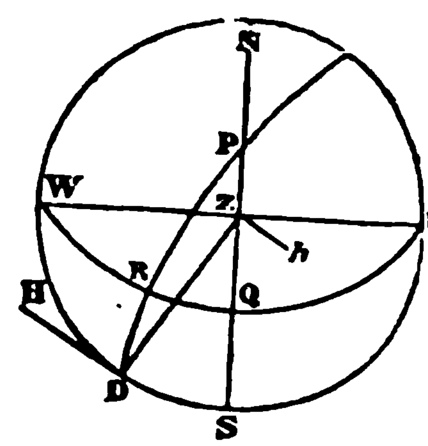
would be a horizontal plane at that place, whose latitude is 30¼ degrees south of the equator, and longitude 42¾ degrees west of the meridian of London.

Which difference of longitude being converted into time, is 2 hours 51 minutes.

The vertical dial declining westward 36 degrees at London, is therefore to be drawn in all respects as a horizontal dial for south latitude 30¼ degrees; save only, that the reckoning of the hours is to anticipate the reckoning on the horizontal dial, by 2 hours 51 minutes: for so much sooner will the sun come to the meridian of London, than to the meridian of any place whose longitude is 42¾ degrees west from London.

2. But to be more exact than the globe will shew us, we shall use a little trigonometry.

Let *N E S W* be the horizon of London, whose zenith is *Z*, and *P* the north pole of the sphere; and let *Z h* be the position of a vertical plane at *Z*, declining westward from *S* (the south) by an angle of 36 degrees; on which plane an erect dial for London at *Z* is to be described.



Make the semidiameter *Z D* perpendicular to *Z h*, and it will cut the horizon in *D*, 36 degrees west of the south *S*. Then, a plane in the tangent *H D*, touching the sphere in *D*, will be parallel to the plane *Z h*; and the axis of the sphere will be equally inclined to both these planes.

Let *W Q E* be the equinoctial, whose elevation above the horizon of *Z* (London) is 38½ degrees; and *P R D* be the meridian of the place *D*, cutting the equinoctial in *R*. Then, it is evident, that the arc *R D* is the latitude of the place *D* (where the plane *Z h* would be horizontal) and the arc *R Q* is the difference of longitude of the planes *Z h* and *D H*.

In the spherical triangle *W D R*, the arc *W D* is given, for it is the complement of the plane's declination from *S* the south; which complement is 54° (viz. 90°—36°:) the angle at *R*, in which the meridian of the place *D* cuts the equator, is a right angle; and the angle *R W D* measures the elevation of the equinoctial above the horizon of *Z*, namely, 38½ degrees. Say therefore, as radius is to the co-sine of the plane's declination from the south, so is the co-sine of the latitude of *Z* to the sine of *R D* the latitude of *D*: which is of a different denomination[113] from the latitude of *Z*, because *Z* and *D* are on different sides of the equator.

As radius.		10.00000
To cosine	36° 0′ = *R Q*	9.90796
So co-sine	51° 30′ = *Q Z*	9.79415

To sine 30° 14′ = *D R* (9.70211) = the latitude of *D*, whose horizon is parallel to the vertical plane *Z h* at *Z*.

N. B. When radius is made the first term, it may be omitted, and then, by subtracting it mentally from the sum of the other two, the operation will be shortened. Thus, in the present case,

To the logarithmic sine of *W R*=54° 0′[114]	9.90796
Add the logarithmic sine of *R D*=38° 30′[115]	9.79415
Their sum — radius	9.70211

gives the same solution as above. And we shall keep to this method in the following part of the work.

To find the difference of longitude of the places *Z* and *Z*, say, as radius is to the co-sine of 38½ degrees, the

Note 113. That is, if the latitude of *Z* be north, that of *D* will be south, and *Y Z* be situated in south latitudes, the latitude of *D* will be north.

Note 114. The co-sine of 36° 0′, or of *R Q*. *Note by the Author.*

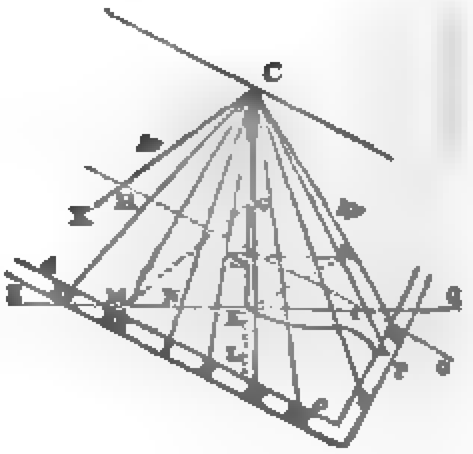
Note 115. The co-sine of 51° 30′, or of *Q Z*.—*Idem.*

LECT. height of the equinoctial at C, so is the co-tangent of 36 degrees, the plane's declination, to the co-tangent of the difference of longitudes. Thus,

To the logarithmic sine of	51° 30'[113]	9.89354
Add the logarithmic tang. of	54° 0'[114]	10.13874
Their sum — radius		10.03228

is the nearest tangent of 47° 8' = $W R$; which is the co-tangent of 42° 52' = $R Q$, the difference of longitude sought. Which difference, being reduced to time, is 2 hours 51½ minutes.

3. And thus having found the exact latitude and longitude of the place *D*, to whose horizon the vertical plane at C is parallel, we shall proceed to the construction of a horizontal dial for the place *D*, whose latitude is 30° 14' south: but anticipating the time at *D* by 2 hours 51 minutes (neglecting the ½ minute in practice) because *D* is so far westward in longitude from the meridian of London; and this will be a true vertical dial at London, declining westward 36 degrees.



Assume any right line *C S L*,[115] for the substile of the dial, and make the angle *K C P* equal to the latitude of the place (viz. 30° 14) to whose horizon the plane of the dial is parallel; then *C R P* will be the axis of the stile, or edge that casts the shadow on the hours of the day, in the dial. This done, draw the contingent

Note 113. The co-sine of 38° 30', or of *W D R*.—*Note by the Author.*

Note 114.—The co-tangent of 36°, or of *D W*. *Idem.*

Note 115. Two parallel lines should be drawn instead of the single line *C S L*, at the distance of the thickness of the gnomon, from each other.

line $E\,Q$, cutting the substilar line at right angles in K; and from K make $K\,R$ perpendicular to the axis $C\,R\,P$. Then $K\,G$ ($=K\,R$) being made radius, that is, equal to the chord of 60° or tangent of 45° on a good sector, take 42° 52′ (the difference of longitude of the places Z and D) from the tangents, and having set it from K to M, draw $C\,M$ for the hour-line of XII. Take $K\,N$ equal to the tangent of an angle less by 15 degrees than $K\,M$; that is, the tangent 27° 52′; and through the point N draw $C\,N$ for the hour-line of I. The tangent of 12° 52′ (which is 15° less than 27° 52′) set off the same way, will give a point between K and N, through which the hour-line of II is to be drawn. The tangent of 2° 8′ (the difference between 45° and 42° 52′) placed on the other side of $C\,L$, will determine the point through which the hour line of III is to be drawn: to which 2° 8′, if the tangent of 15° be added, it will make 17° 8′; and this set off from K towards Q on the line $E\,Q$, will give the point for the hour-line of IV: and so of the rest.—The forenoon hour-lines are drawn the same way, by the continual addition of the tangents 15°, 30°, 45°, &c. to 42° 52′ (= the tangent of $K\,M$) for the hours of XI, X, IX, &c. as far as necessary; that is, until there be five hours on each side of the substile. The sixth hour, accounted from that hour or part of the hour on which the substile falls, will be always in a line perpendicular to the substile, and drawn through the center C.

4. In all erect dials, $C\,M$, the hour-line of XII, is perpendicular to the horizon of the place for which the dial is to serve: for that line is the intersection of a vertical plane with the plane of the meridian of the place, both which are perpendicular to the plane of the horizon: and any line $H\,O$, or $h\,o$, perpendicular to $C\,M$, will be a horizontal line on the plane of the dial, along which line the hours may be numbered; and $C\,M$

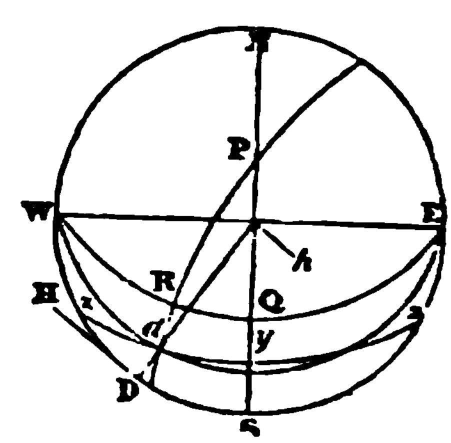
LECT. XI being set perpendicular to the horizon, the dial will have its true position.

5. If the plane of the dial had declined by an equal angle toward the east, its description would have differed only in this, that the hour-line of XII would have fallen on the other side of the substile $C L$, and the line $H O$ would have a sub-contrary position to what it has in this figure.

6. And these two dials, with the upper points of their stiles turned toward the north-pole, will serve for the other two planes parallel to them; the one declining from the north toward the east, and the other from the north toward the west, by the same quantity of angle. The like holds true of all dials in general, whatever be their declination and obliquity of their planes to the horizon.

CASE II.

7. If the plane of the dial not only *declines*, but also *reclines*, or *inclines*. Suppose its declination from fronting the south S be equal to the arc $S D$ on the horizon: and its reclination be equal to the arc $D d$ of the vertical circle $D Z$: then it is plain, that if the quadrant of altitude $Z d D$, on the globe, cuts the point D in the horizon, and the reclination is counted upon the quadrant from D to d; the intersection of the hour-circle $P R d$, with the equinoctial $W Q E$, will determine $R d$, the latitude of the place d, whose horizon is parallel to the given plane $Z h$ at Z; and $R Q$ will be the difference in longitude of the planes at d and Z.



Trigonometrically thus: let a great circle pass through the three points W, d, E; and in the triangle $W D d$, right-angled at D, the sides $W D$ and $D d$ are

given; and thence the angle $D W d$ is found, and so is the hypothen use $W d$. Again, the difference, or the sum, of $D W d$ and $D W R$, the elevation of the equinoctial above the horizon of D, gives the angle $d W R$, and the hypothenuse of the triangle $W R d$ was just now found; whence the sides $R d$ and $W R$ are found, the former being the latitude of the place d, and the latter the complement of $R Q$, the difference of longitude sought. LECT XL.

Thus, if the latitude of the place Z be 52° 10′ north; the declination $S D$ of the plane $Z h$ (which would be horizontal at d) be 36°, and the reclination be 15°, or equal to the arc $D d$; the south latitude of the place d, that is, the arc $R d$, will be 15° 9′; and $R Q$, the difference of the longitude, 36° 2′. From these data, therefore, let the dial (fig. 4.) be described as in the former example.

8. Only it is to be observed, that in the reclining or inclining dials, the horizontal line will not stand at right angles to the hour-line of XII, as in erect dials; but its position may be found as follows.

To the common substilar line $C K L$, on which the dial for the place d (in the preceding engraving, page 376) was described, draw the dial $C r p m$ 12 for the place D, whose declination is the same as that of d (viz. the arc $S D$:) and $H O$, perpendicular to $C m$, the hour-line of XII on this dial, will be a horizontal line on the dial $C P R M$ XII. For the declination of both dials being the same, the horizontal line remains parallel to itself, while the erect position of one dial is reclined or inclined with respect to the position of the other.

Or, the position of the dial may be found by applying it to its plane, so as to mark the true hour of the day by the sun, as shewn by another dial; or by a clock, regulated by a true meridian line and equation table.

9. There are several other things requisite in the practice of dialing; the chief of which I shall give in

LECT. XI. the form of arithmetical rules, simple and easy to those who have learned the elements of trigonometry. For in practical arts of this kind, arithmetic should be used as far as it can go; and scales never trusted to, except in the final construction, where they are absolutely necessary in laying down the calculated hour-distances on the plane of the dial. And although the inimitable artists of this metropolis have no occasion for such instructions, yet they may be of some use to students, and to private gentlemen who amuse themselves this way.

RULE I.

To find the angles which the hour-lines on any dial make with the substile.

To the logarithmic sine of the given latitude, or of the stile's elevation above the plane of the dial, add the logarithmic tangent of the hour distant from the meridian,[116] or from the substile;[117] and the sum *minus* radius will be the logarithmic tangent of the angle sought.

For, in fig. 2. KC is to KM in the ratio compounded of the ratio of KC to KG ($= KR$) and of KG to KM; which, making CK the radius, 10,000000, or 10,0000, or 10, or 1, are the ratio of 10,000000, or of 10,0000 or of 10, or of 1, to $KG \times KM$.

Thus, in a horizontal dial, for latitude 51° 30′, to find the angular distance of XI in the forenoon, or I in the afternoon, from XII.

Note 116. That is, of 15, 30, 45, 60, 75°, for the hours of I, II, III, IIII, V in the afternoon: and XI, X, IX, VIII, VII in the forenoon. *Note by the Author.*

Note 117. In all horizontal dials, the erect north or south dials, the substile and meridian are the same: but in all declining dials, the substile line makes an angle with the meridian. *Idem.*

To the logarithmic sine of 51° 30′ 9.89354[118]
Add the logarithmic tang. of 15° 0′ 9.42805

The sum—radius is . . . . 9.32159= the logarithmic tangent of 11° 50′, or of the angle which the hour-line of XI or I makes with the hour-line of XII.

And by computing in this manner, with the sine of the latitude, and the tangents of 30, 45, 60, and 75°, for the hours of II, III, IIII, and V in the afternoon: or of X, IX, VIII, and VII in the forenoon; you will find, their angular distances from XII to be 24° 18′, 38° 3′, 53° 35′, and 71° 6′; which are all that there is occasion to compute for.——And these distances may be set off from XII by a line of chords; or rather, by taking 1000 from a scale of equal parts, and setting that extent as a radius from *C* to XII; and then, taking 209 of the same parts (which, in the tables, are the natural tangent of 11° 50′) and setting them from XII to XI and to I, on the line *h o*, (see engraving, page 374) which is perpendicular to *C* XII: and so for the rest of the hour-lines which, in the table of natural tangents, against the above distances, are 451, 782, 1355, and 2920, of such equal parts from XII, as the radius *C* XII contains 1000. And lastly, set off 1257 (the natural tangent of 51° 30′) for the angle of the stile's height, which is equal to the latitude of the place.

The reason why I prefer the use of the tabular numbers, and of a scale decimally divided, to that of the line of chords, is because there is the least chance of mistake and error in this way; and likewise, because in some cases it gives us the advantage of a *nonius'* division.

Note 118. In which case, the radius *C K* is supposed to be divided into 1000000 equal parts. *Note by the Author.*

LECT. XI.

In the universal ring-dial, for instance, the divisions on the axis are the tangents of the angles, of the sun's declination placed on either side of the center. But instead of laying them down from a line of tangents, I would make a scale of equal parts, whereof 1000 should answer exactly to the length of the semi-axis, from the center to the inside of the equinoctial ring; and then lay down 434 of these parts toward each end from the center, which would limit all the divisions on the axis, because 434 are the natural tangent of 23° 29′. And thus, by a *nonius* affixed to the sliding piece, and taking the sun's declination from an Ephemeris, and the tangent of that declination from the table of natural tangents, the slider might be always set true to within two minutes of a degree.

And this scale of 434 equal parts might be placed right against the $23\frac{1}{2}$ degrees of the sun's declination, on the axis, instead of the sun's place, which is there of very little use. For then, the slider might be set in the usual way, to the day of the month, for common use; but to the natural tangent of the declination, when great accuracy is required.

The like may be done wherever a scale of sines or tangents is required on any instrument.

RULE II.

The latitude of the place, the sun's declination, and his hour distance from the meridian, being given; to find, (1.) *his altitude;* (2.) *his azimuth.*

Let d (see engraving, page 372) be the sun's place, $d\,R$, his declination; and in the triangle $P\,Z\,d$, $P\,d$ the sum, or the difference, of $d\,R$, and the quadrant $P\,R$, being given by the supposition, as also the complement of the latitude $P\,Z$, and the angle $d\,P\,Z$, which measures the horary distance of d from the meridian;

we shall by Case 4. of *Keill's* Oblique Spheric Trigonometry) find the base Zd, which is the sun's distance from the zenith, or the complement of his altitude.

And (2.) As sine Zd: sine Pd: sine dPZ; dZP, or of its supplement DZS, the azimuthal distance from the south.

Or, the practical rule may be as follows.

Write A for the sine of the sun's altitude, L and l for the sine and co-sine of the latitude, D and d for the sine and co-sine of the sun's declination, and H for the sine of the horary distance from VI.

Then the relation of H to A will have three varieties.

1. When the declination is toward the elevated pole, and the hour of the day is between XII and VI; it is

$A = LD + Hld$, and $H = \frac{A - LD}{ld}$.

2. When the hour is after VI, it is $A = LD - Hld$, and $H = \frac{LD - A}{ld}$.

3. When the declination is toward the depressed pole, we have $A = Hld - LD$, and $H = \frac{A + LD}{ld}$

Which theorems will be found useful, and expeditious enough for solving those problems in geography and dialing, which depend on the relation of the sun's altitude to the hour of the day.

EXAMPLE I.

Suppose the latitude of the place to be 51½ degrees north; the time five hours distant from XII, that is, an hour after VI in the morning, or before VI in the evening; and the sun's declination 20° north. *Required the sun's altitude?*

LECT. X.

Then, to log. L=log. sin. 51° 30′ 1.89354[119]
add log. D=log. sin. 20° 0′ 1.53405

Their sum 1.42759

gives $L\,D$=logarithm of 0.267664, in the natural sines.

And, to log. H=log. sin. 15° 0′[120] 1.41300
add { log. l= log. sin. 38° 0′[121] 1.79414
log. d= log. sin. 70° 0′[122] 1.97300

Their sum 1.18015

gives $H\,l\,d$=logarithm of 0.151408, in the natural sines.

And these two numbers (0.267664 and 0.151408) make 0.419072=A; which, in the table, is the nearest natural sine of 24° 47′, the sun's altitude sought.

The same hour-distance being assumed on the other side of VI, then $L\,D-H\,l\,d$ is 0.116256, the sine of 6° 40¼′; which is the sun's altitude at V in the morning, or VII in the evening, when his north declination is 20°.

But when the declination is 20° south (or towards the depressed pole) the difference $H\,l\,d-L\,D$ becomes negative, and thereby shews that, an hour before VI in the morning, or past VI in the evening, the sun's center is 6° 40¼′ below the horizon.

EXAMPLE II.

In the same latitude and north declination, from the given altitude to find the hour.

Note 119. Here we consider the radius as unity, and not 10.000, by which, instead of the index 9 we have—1, as above: which is of no farther use, than making the work a little easier. *Note by the Author.*

Note 120. The distance of one hour from VI. *Idem.*

Note 121. The co-latitude of the place. *Idem.*

Note 122. The co-declination of the sun. *Idem.*

Let the altitude be 48°; and because, in this case, $H=\frac{A-LD}{ld}$, and A (the natural sine of 48°)$=743145$, and $LD=.267664$, $A-LD$ will be 0.475481,

whose logarithmic sine is	1.6771331
from which taking the logarithmic sine of	
$l \times d=$	1.7671354
Remains	1.9099977

the logarithmic sine of the hour-distance sought, viz. of 54° 22′: which, reduced to time, is 3 hours $37\frac{1}{2}$ min. that is, IX h. $37\frac{1}{2}$ min. in the forenoon, or II h. $22\frac{1}{2}$ m. in the afternoon.

Put the altitude $=18°$, whose natural sine is .3090170; and thence $A-LD$ will be $=.0491953$; which divided by $l \times d$, gives .0717179, the sine of 4° 6′, in time $16\frac{1}{2}$ minutes nearly, before VI in the morning, or after VI in the evening, when the sun's altitude is 18°.

And, if the declination 20° had been towards the south pole, the sun would have been depressed 18° below the horizon at $16\frac{1}{2}$ minutes after VI in the evening: at which time, the twilight would end; which happens about the 22d of November, and 19th of January, in the latitude of $51\frac{1}{2}$° north. The same way may the end of twilight, or beginning of dawn, be found for any time of the year.

NOTE 1. If in theorems 2 and 3 (page 363) A is put $=0$, and the value of H is computed, we have the hour of sun-rising and setting for any latitude, and time of the year. And if we put $H=0$, and compute A, we have the sun's altitude or depression at the hour of VI. And lastly, if H, A and D are given, the latitude may be found by the resolution of a quadratic equation; for $l=\sqrt{1-L^2}$.

NOTE 2. When A is equal 0, H is equal $\frac{LD}{ld}=$ $TL \times TD$, the tangent of the latitude multiplied by the tangent of the declination.

LECT. XI.

As, if it was required, *what is the greatest length of day in latitude* 51° 30′?

To the log. tangent of 51° 30′ 0.0993948
Add the log. tangent of 23° 29′ 1.6379563

Their sum . . . . . . 1.7373511 is the log. sine of the hour-distance 33° 7′; in the time 2 h. 12½ m. The longest day therefore is 12 h. + 4 h. 25 m. = 16 h. 25 m. And the shortest day is 12 h.—4 h. 25 m.=7 h. 35 m.

And if the longest day is given, the latitude of the place is found; $\frac{H}{TD}$ being equal to TL. Thus, if the longest day is 13½ hours = 2× 6 h. + 45 m. and 45 minutes in time being equal to 11¼ degrees.

From the log. sine of 11° 15′ 1.2902357
Take the log. tang of 23° 29′ 1.6379562

Remains 1.9522795
=the logarithmic tangent of lat. 24° 11′.

And the same way, the latitudes, where the several geographical *climates* and parallels begin, may be found; and the latitudes of places, that are assigned in authors from the length of their days, may be examined and corrected.

NOTE 3. The same rule for finding the longest day in a given latitude, distinguishes the hour-lines that are necessary to be drawn on any dial from those which would be superfluous.

In lat. 52° 10′ the longest day is 16 h. 32 m. and the hour-lines are to be marked from 44 m. after III in the morning, to 16 m. after VIII in the evening.

In the same latitude, let the dial of Art. 7. fig. 4. be proposed; and the elevation of its stile (or the latitude of the place *d*, (see engraving, page 376,) whose horizon is parallel to the plane of the dial) being 15° 9′; the longest day at *d*, that is, the longest time that the sun

can illuminate the plane of the dial, will (by the rule $H = TL \times TD$) be twice 6 hours 27 minutes= 12 h. 54 m. The difference of longitude of the planes *d* and *Z* was found in the same example to be 36° 2′: in time, 2 hours 24 minutes; and the declination of the plane was from the south towards the west. Adding therefore 2 h. 24 min. to 5 h. 33 m. the earliest sun-rising on a horizontal dial at *d*, the sum 7 h. 57 min. shews that the morning hours, or the parallel dial at *Z*, ought to begin at 3 min. before VIII. And to the latest sun-setting at *d*, which is 6 h. 27 m. adding the same 2 h. 24 m. the sum 8 h. 51 m. exceeding 6 h. 16 m. the latest sun-setting at *Z*, by 35 m. shews that none of the afternoon hour-lines are superfluous. And the 4 h. 13 m. from III h. 44 m. the sun-rising at *Z* to VII h. 57 m. the sun-rising at *d*, belong to the other face of the dial; that is, to a dial declining 36° from north to east, and inclining 15°.

EXAMPLE III.

From the same *data* to find the sun's *azimuth*.

If *H, L* and *D* are given, then (by Art. 2. of Rule II.) from *H* having found the altitude and its complement *Z d;* and the arc *P d* (the distance from the pole) being given: say, As the co-sine of the altitude is to the sine of the distance from the pole, so is the sine of the hour-distance from the meridian to the sine of the azimuth-distance from the meridian.

Let the latitude be 51°.30′ north, the declination 15° 9′ south, and the time II h. 24 m. in the afternoon, when the sun begins to illuminate a vertical wall, and it is required to find the position of the wall.

Then, by the foregoing theorems, the complement of the altitude will be 81° 32′, and *P d* the distance from

LECT. X. the pole being 109° 5′, and the horary distance from the meridian, or the angle dPZ, 36°.

To log. sin. 74° 51′ . . .	1.98464
Add log. sin. 36° 0′ . . .	1.76922
And from the sum . . .	1.75386
Take the log. sin. 81° 32½′	1.99525
Remains	1.75861 ± log.

sin. 35°, the azimuth distance south.[127]

When the altitude is given, find from thence the hour, and proceed as above.

This praxis is of singular use on many occasions; in finding the declination of vertical planes more exactly than in the common way, especially if the transits of the sun's center are observed by applying a ruler with sights, either plain or telescopical, to the wall or plane, whose declination is required.—In drawing a meridian-line, and finding the magnetic variation—In finding the bearings of places in terrestrial surveys; the transits of the sun over any place, or his horizontal distance from it being observed, together with the altitude and hour.—And thence determining small differences of longitude.—In observing the variation at sea, &c.

The learned *Mr. Andrew Reid* invented an instrument several years ago, for finding the latitude at sea from two altitudes of the sun, observed on the same day, and the interval of the observations, measured by a common watch. And this instrument, whose only fault was that of its being somewhat expensive, was made by *Mr. Jackson*. Tables have been lately computed for that purpose.

Note 127. In all these calculations the angles are taken out to the nearest minute only: for the method of performing these calculations more exactly, see the Introduction to Hutton's Mathematical Tables. For calculations, like those used in dialing, which do not require very great exactness, a small collection of Tables has been published by Mr. Whiting of Brompton, highly commendable for their elegance and moderate price.

But we may often, from the foregoing rules, resolve the same problem without much trouble; especially if we suppose the master of the ship to know within 2 or 3 degrees what his latitude is. Thus,

Assume the two nearest probable limits of the latitude, and by the theorem $H=\frac{A+LD}{ld}$ compute the hours of observation for both suppositions. If one interval of those computed hours coincides with the interval observed, the question is solved. If not, the two distances of the intervals computed, from the true interval, will give a proportional part to be added to, or subtracted from, one of the latitudes assumed. And if more exactness is required, the operation may be repeated with the latitude already found.

But whichever way the question is solved, a proper allowance is to be made for the difference of latitude arising from the ship's course in the time between the two observations.

Of the double horizontal dial; and the Babylonian *and* Italian *dials.*

To the *gnomonic* projection, there is sometimes added a *stereographic* projection of the hour-circles, and the parallels of the sun's declination, on the same horizontal plane; the upright side of the gnomon being sloped into an edge, standing perpendicularly over the center of the projection: so that the dial, being in its due position, the shadow of *that* perpendicular edge is a vertical circle passing through the sun, in the stereographic projection.

The months being duly marked on this dial, the sun's declination, and the length of the day at any time, are had by inspection (as also his altitude, by means of a scale of tangents.) But its chief property is, that it may

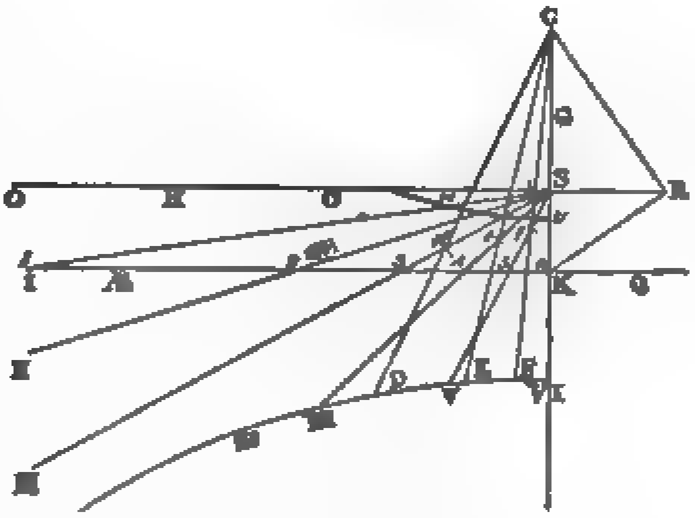
LECT. XI. be placed true, whenever the sun shines, without the help of any other instrument.

Let *d* (see engraving, p. 376) be the sun's place in the stereographic projection. *x d y z* the parallel of the sun's declination. *Z d* a vertical circle through the sun's center. *P d* the hour-circle: and it is evident, that the diameter N S of this projection being placed duly north and south, these three circles will pass through the point *d*. And therefore, to give the dial its due position, we have only to turn its gnomon toward the sun, on a horizontal plane, until the hour on the common gnomonic projection coincides with that marked by the hour-circle *P d*, which passes through the intersection of the shadow *Z d* with the circle of the sun's present declination.

The *Babylonian* and *Italian* dials reckon the hours, not from the meridian, as with us, but from the sun's rising and setting. Thus, (plate 8) in *Italy*, an hour before sun-set is reckoned the 23d hour; two hours before sun-set, the 22d hour; and so of the rest. And the shadow that marks them on the hour-lines, is *that* of the point of a stile. This occasions a perpetual variation between their dials and clocks, which they must correct from time to time, before it arises to any sensible quantity, by setting their clocks so much faster or slower. And in *Italy*, they begin their day, and regulate their clocks, not from sun-set, but from about mid-twilight, when the *Ave Maria* is said; which corrects the difference that would otherwise be between the clock and the dial.

The improvements which have been made in all sorts of instruments and machines for measuring time, have rendered such dials of little account. Yet, as the theory of them is ingenious, and they are really, in some respects, the best contrived of any for vulgar use, a general idea of their description may not be unacceptable.

Let this figure represent an erect direct south-wall, on which a *Babylonian Dial* is to be drawn, shewing the hours from sun-rising; the latitude of the place, whose horizon is parallel to the wall, being equal to the angle KCR. Make, as for a common dial $KG=KR$ (which is perpendicular to CR) the radius of the equinoctial $ÆQ$, and draw RS perpendicular to CK for the stile of the dial; the shadow of whose point R is to mark the hours, when SR is set upright on the plane of the dial.



Then it is evident, that in the contingent line $ÆQ$, the spaces $K\,1$, $K\,2$, $K\,3$, &c. being taken equal to the tangents of the hour-distances from the meridian, to the radius KG, one, two, three, &c. hours after sun-rising, on the equinoctial day; the shadow of the point R will be found, at these times, respectively in the points 1, 2, 3, &c.

Draw, for the like hours after sun-rising, when the sun is in the tropic of Capricorn ♑ V, the like common lines CD, CE, CF, &c. and at these hours the shadow of the point R will be found in those lines respectively. Find the sun's altitudes above the plane of the dial at these hours, and with their co-tangents Sd, Se, Sf, &c. to radius SR, describe arcs intersecting the hour-lines in the points d, e, f, &c. so shall the right lines $1\,d$, $2\,e$, $3\,f$, &c. be the lines of I, II, III, &c. hours after sun-rising.

The construction is the same in every other case, due regard being had to the difference of longitude of the

LECT. XI.

plane in which the dial would be horizontal, and the plane for which it is to serve. And likewise, taking care to draw no lines but what are necessary: which may be done partly by the rules already given for determining the time that the sun shines on any plane; and partly from this, that on the tropical days, the hyperbola described by the shadow of the point *R*, limits the extent of all the hour-lines.

The most useful, however, as well as the simplest of such dials, is that which is described on the two sides of a meridian plane.

That the *Babylonish* and *Italian* hours are truly enough marked by right lines, is easily shewn. Mark the three points on a globe, where the horizon cuts the equinoctial, and the two tropics, toward the east or west; and turn the globe on its axis 15°, or 1 hour: and it is plain, that the three points which were in a great circle (viz. the horizon) will be in a great circle still; which will be projected geometrically into a straight line. But these three points are universally the sun's places, one hour after sun-set (or one hour before sun-rise) on the equinoctial and solstitial days. The like is true of all other circles of declination, besides the tropics: and therefore, the hours on such dials are truly marked by straight lines limited by the projections of the tropics; and which are rightly drawn, as in the foregoing example.

Note 1. The same dials may be delineated without the hour-lines *C D*, *C E*, *C F*, &c. by setting off the sun's azimuths on the plane of the dial, from the center *S*. on either side of the substile *C S K*, and the corresponding co-tangents of altitude from the same center *S*, for I. II, III, &c. hours before or after the sun is in the horizon of the place for which the dial is to serve, on the equinoctial and solstitial days.

2. One of these dials has its name from the hours being reckoned from sun-rising, the beginning of the

Babylonian day. But we are not thence to imagine that the *equal* hours, which it shews, were those in which the astronomers of that country marked their observations. These, we know with certainty, were unequal, like the *Jewish*, as being twelfth parts of the natural day: and an hour of the night was, in like manner, a twelfth part of the night; longer or shorter, according to the season of the year. So that an hour of the day, and an hour of the night, at the same place, would always make $\frac{1}{12}$ of 24, or 2 equinoctial hours. In *Palestine*, among the *Romans*, and in several other countries, 3 of these unequal nocturnal hours were a *vigilia* or *watch*. And the reduction of equal and unequal hours into one another, is extremely easy. If, for instance, it is found, by a foregoing rule, that in a certain latitude, at a given time of the year, the length of a day is 14 equinoctial hours, the unequal hour is then $\frac{14}{12}$ or $\frac{7}{6}$ of an hour, that is, 70 minutes; and the nocturnal hour is 50 minutes. The first watch begins at VII (sun-set;) the second at three times 50 minutes after, viz. IX h. 30 m. the third always at midnight; the morning watch at $\frac{1}{2}$ hour past II.

If it were required to draw a dial for shewing these unequal hours, or 12th parts of the day, we must take as many declinations of the sun as are thought necessary, from the equator towards each tropic: and having computed the sun's altitude and azimuth for $\frac{1}{12}$, $\frac{2}{12}$, $\frac{3}{12}$ parts, &c. of each of the diurnal arcs belonging to the declinations assumed: by these, the several points in the circles of declination, where the shadow of the stile's point falls, are determined: and curve lines drawn through the points of an homologous division will be the hour-lines required.

Of the right placing of Dials, and having a true meridian line for the regulating of clocks and watches.

The plane on which the dial is to rest, being duly

LECT XI. prepared, and every thing necessary for fixing it, you may find the hour tolerably exact by a large equinoctial ring-dial, and set your watch to it. And then the dial may be fixed by the watch at your leisure.

If you would be more exact, take the sun's altitude by a good quadrant, noting the precise time of observation by a clock or watch. Then, compute the time for the altitude observed, (by the rule already described,) and set the watch to agree with that time, according to the sun. A *Hadley's* quadrant is very convenient for this purpose; for, by it you may take the angle between the sun and his image, reflected from a bason of water: the half of which angle, subtracting the refraction, is the altitude required. This is best done in summer, and the nearer the sun is to the prime vertical (the east or west azimuth) when the observation is made, so much the better.

Or, in summer, take two equal altitudes of the sun in the same day; one any time between 7 and 10 o'clock in the morning, the other between 2 and 5 in the afternoon; noting the moments of these two observations by a clock or watch: and if the watch shews the observations to be at equal distances from noon, it agrees exactly with the sun; if not, the watch must be corrected by half the difference of the forenoon and afternoon intervals; and then the dial may be set true by the watch.

Thus, for example, suppose you have taken the sun's altitude when it was 20 minutes past VIII in the morning by the watch; and found, by observing in the afternoon, that the sun had the same altitude 10 minutes before IV; then it is plain, that the watch was 5 minutes too fast for the sun: for 5 minutes after XII is the middle time between VIII h. 20 m. in the morning, and IV. h. 50 m. in the afternoon; and therefore, to make the watch agree with the sun, it must be set back five minutes.

A good *meridian line*, for regulating clocks or watches, may be had by the following method.

A meridian line.

Make a round hole, almost a quarter of an inch diameter, in a thin plate of metal; and fix the plate in the top of a south window, in such a manner, that it may recline from the zenith at an angle equal to the co-latitude of your place, as nearly as you can guess; for then, the plate will face the sun directly at noon on the equinoctial days. Let the sun shine freely through the hole into the room; and hang a plumb-line to the ceiling of the room, at least five or six feet from the window, in such a place that the sun's rays, transmitted through the hole, may fall upon the line when it is noon by the clock; and having marked the said place on the ceiling, take away the line.

Having adjusted a sliding bar to a dove-tail groove, in a piece of wood about 18 inches long, and fixed a hook into the middle of the bar, and nailed the wood to the above-mentioned place on the ceiling, parallel to the side of the room in which the window is: the groove and bar being towards the floor. Then, hang the plumb-line upon the hook in the bar, the weight or plummet reaching almost to the floor; and the whole will be prepared for farther and proper adjustment.

This done, find the true solar time by either of the two last methods, and thereby regulate your clock. Then, at the moment of next noon by the clock, when the sun shines, move the sliding bar in the groove until the shadow of the plumb-line bisects the image of the sun (made by his rays transmitted through the hole) on the floor, wall, or on a white screen placed on the north side of the line; the plummet or weight at the end of the line hanging freely in a pail of water placed below it on the floor.—But because this may not be quite correct for the first time, on account that the plummet will not settle immediately, even in water; it may be farther corrected on the following days, by the above method,

LECT. XI. with the sun and clock; and so brought to a very great exactness.

N. B. The rays transmitted through the hole, will cast but a faint image of the sun, even on a white screen, unless the room be so darkened that no sun-shine may be allowed to enter, but what comes through the small hole in the plate. And always, for some time before the observation is made, the plummet ought to be immersed in a jar of water, where it may hang freely; by which means the line will soon become steady, which otherwise would be apt to continue swinging.

As this meridian line will not only be sufficient for regulating of clocks and watches to the true time by equation tables, but also for most astronomical purposes, I shall say nothing of the magnificent and expensive meridian lines at *Bologna* and *Rome*, nor of the better methods by which astronomers observe precisely the transits of the heavenly bodies on the meridian.

LECTURE XII.

Shewing how to calculate the mean time of any New or Full Moon, or Eclipse, from the creation of the world to the year of CHRIST 5800.

In the following tables, the mean lunation is about a 20th part of a second of time longer than its measure as now printed in the third edition of my Astronomy; which makes a difference of an hour and 30 minutes in 6000 years.—But this is not material, when only the mean times are required.

PRECEPTS.

To find the mean time of any New or Full Moon in any given year and month after the Christian Æra.

1. If the given year be found in the third column of the *Table of the moon's mean motion from the sun,* under the title *Years before and after* CHRIST; write out that year, with the mean motions belonging to it, and thereto join the given month with its mean motions. But, if the given year be not in the table, take out the next lesser one to it that you find, in the same column; and thereto add as many *complete years,* as will make up the given year: then, join the given month, and all the respective mean motions.

2. Collect these mean motions into one sum of signs, degrees, minutes, and seconds; remembering, that 60 seconds (″) make a minute, 60 minutes (′) a degree, 30 degrees (°) a sign, and 12 signs (ˢ) a circle. When the signs exceed 12, or 24, or 36 (which are whole circles) reject them, and set down only the remainder; which together with the odd degrees, minutes, and seconds

LECT. XII. already set down, must be reckoned the whole sum of the collection.

3. Subtract the result, or sum of this collection, from 12 signs; and write down the remainder. Then, look in the table, under *Days*, for the next less mean motions to this remainder, and subtract them from it, writing down their remainder.

This done, look in the table under *hours* (marked H) for the next less mean motions to this last remainder, and subtract them from it, writing down their remainder.

Then look in the table under *minutes* (marked M) for the next less mean motions to this remainder, and subtract them from it, writing down their remainder.

Lastly, look in the table under *seconds* (marked S) for the next less mean motions to this remainder, either greater or less; and against it you have the seconds answering thereto.

4. And these times collected, will give the mean time of the *required new moon;* which will be right in common years, and also in January and February in leap-years: but always one day too late in leap-years after February.

EXAMPLE I.

Required the time of new moon in September, 1764?

(a year not inserted in the table.)

		Moon from sun. s	°	′	″
To the year after *Christ's* birth	1753	10	9	24	56
Add complete years	11	0	10	14	20
	(sum 1764)				
And join September		2	22	21	8
The sum of these mean motions is . . .		1	12	0	24
Which, being subtracted from a circle, or		12	0	0	0
Leaves remaining		10	17	59	36
Next less mean motion for 26 d. subtract		10	16	57	34
And there remains		0	1	2	2
Next less mean motion for 2 h. subtract		0	1	0	57
And the remainder will be		0	0	1	5
Next less mean motion for 2 m. subtract		0	0	1	1
Remains the mean motion of 12 sec. .		0	0	0	4

These times, being collected, would shew the mean time of the required new moon in September 1764, to be on the 26th day, at 2 hours 2 min. 12 sec. past noon. But, as it is in a leap-year, and after February, the time is one day too late. So, the true mean time is September the 25th. at 2 min. 12 sec. past II in the afternoon.

N. B. The tables always begin the day at noon, and reckon thence forward, to the noon of the day following.

LECT XII.

To find the mean time of full moon in any given year and month after the Christian Æra.

Having collected the moon's mean motion from the sun for the beginning of the given year and month, and subtracted their sum from 12 signs (as in the former example) add 6 signs to the remainder, and then proceed in all respects as above.

EXAMPLE II.

Required the mean time of full Moon in September, 1764?

		Moon from sun.			
		s	°	′	″
To the year after *Christ's* birth	1753	10	9	24	56
Add complete years . .	11	0	10	14	20
	(sum 1764)				
And join September		2	22	21	8
The sum of these mean motions is . .		1	12	0	24
Which, being subtract. from a circle, or		12	0	0	0
Leaves remaining		10	17	59	36
To which remainder add		6	0	0	0
And the sum will be		4	17	59	36
Next less mean motion for 11 d. subtract		4	14	5	54
And there remains		0	3	53	42
Next less mean motion for 7 h. subtract		0	3	33	20
And the remainder will be		0	0	20	22
Next less mean motion for 40 m. subtract		0	0	20	19
Remains the mean motion for 8 sec. .		0	0	0	3

So, the mean time, according to the tables, is the 11th

of September, at 7 hours 40 minutes 8 seconds past noon. One day too late, being after February in a leap-year.

And thus may the mean time of any new or full moon be found, in any year after the Christian Æra.

To find the mean time of new or full moon in any given year and month before the Christian Æra.

If the given year before the year of CHRIST 1. be found in the third column of the table, under the title *Years before and after* CHRIST, write it out, together with the given month, and join the mean motions. But, if the given year be not in the table, take out the next greater one to it that you find; which being still farther back than the given year, add as many complete years to it as will bring the time forward to the given year; then join the month, and proceed in all respects as above.

EXAMPLE III.

Required the mean time of new moon in May, the year before Christ, 585?

The next greater year in the table is 600; which being 15 years before the given year, add the mean motion for 15 years to those of 600, together with those for the beginning of May.

	Moon from sun.			
	s	°	′	″
To the year before *Christ* 600	5	11	6	16
Add complete years motion 15	6	0	55	24
And the mean motions for May . . .	0	22	53	23
The whole sum is	0	4	55	3
Which, being subt. from a circle, or .	12	0	0	0

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	Mean from sun.			
	s	°	'	"
Leaves remaining	11	25	4	57
Next less mean motion for 29 days, subt.	11	23	31	54
And there remains	0	1	33	3
Next less mean motion for 3 hours subt.	0	1	31	26
And the remainder will be	0	0	1	37
Next less mean motion for 3 min. subt.	0	0	1	31
Remains the mean motion of 14 seconds	0	0	0	6

So, the mean time by the tables, was the 29th of May, at 3 hours 3 min. 14 sec. past noon. A day later than the truth, on account of its being in a leap-year. For as the year of CHRIST 1. was the first after a leap-year, the year 585 before the year 1, was a leap-year of course.

If the given year be after the Christian Æra, divide its date by 4, and if nothing remains, it is a leap-year in the old stile. But if the given year was before the Christian Æra, or Year of CHRIST 1, subtract one from its date, and divide the remainder by 4; then, if nothing remains, it was a leap-year; otherwise not.

To find whether the sun is eclipsed at the time of any given change, or the moon at any given full.

Of eclipses. From the *Table of the sun's mean motion* or distance, *from the moon's ascending node,* collect the mean motions answering to the given time; and if the result shews the sun to be within 18 degrees of either of the nodes at the time of new moon, the sun will be eclipsed at that time. Or, if the result shews the sun to be within 12 degrees of either of the nodes at the time of full moon, the moon will be eclipsed at that time, in or near the contrary node; otherwise not.

EXAMPLE IV

The moon changes on the 26th of September 1764, *at* 2 *h.* 2 *m. (neglecting the seconds) afternoon.* (See Example I.) *Qu. Whether the sun will be eclipsed at that time?*

		Sun from node.			
		s	°	′	″
To the year after *Christ's* birth	1753	1	28	0	19
Add complete years . . .	11	7	2	3	56
	(sum 1764)				
And September		8	12	22	49
26 days			27	0	13
2 hours		0	0	5	12
2 minutes		0	0	0	5
Sun's distance from the ascending node .		6	9	32	34

Now, as the descending node is just opposite to the ascending, (viz. 6 signs distant from it) and the tables show only how far the sun has gone from the ascending node, which, by this example, appears to be 6 signs 9 degrees 32 minutes 34 seconds, it is plain that he must be eclipsed; being then only 9° 32′ 34″ short of the descending node.

EXAMPLE V.

The moon will be full on the 11*th of September*, 1764, *at* 7 *h.* 40 *m. past noon.* (See Example II.) *Qu. Whether she will be eclipsed at that time?*

		Sun from node.			
		s	°		″
To the year after *Christ's* birth	1753	1	28	0	19
Add complete years	11	7	2	3	56
	(sum 1764)				

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	Sun from node.			
	s	°	′	″
And { September	8	12	22	49
11 days	0	11	25	29
7 hours	0	0	18	11
40 minutes	0	0	1	44
Sun's distance from the ascending node	5	24	12	28

Which being subtracted from 6 signs, leaves only 5° 47′ 32″ remaining; and this being all the space that the sun is short of the descending node, it is plain that the moon must then be eclipsed, because she is just as near the contrary node.

EXAMPLE VI.

Q. *Whether the sun was eclipsed in May, the year before* CHRIST, 585? (See Example III.)

	Sun from node.			
	s	°	′	″
To the year before *Christ* 600 . . .	9	9	23	51
Add the mean motion of 15 complete years	9	19	27	48
And { May	4	4	37	57
29 days	1	0	7	10
3 hours	0	0	7	48
3 minutes (neglecting the	0	0	0	0
seconds)	0	0	0	8
Sun's distance from the ascending node	0	3	44	43

Which being less than 18 degrees, shews that the sun was eclipsed at that time.

This eclipse was foretold by *Thales*, and is thought to be the eclipse which put an end to the war between the Medes and Lydians.

The times of the *sun's conjunction with the nodes,* and consequently the *eclipse-months* of any given year, are easily found by the *Table of the sun's mean motion from*

the moon's ascending node; and much in the same way as the mean conjunctions of the sun and moon are found by the table of the moon's mean motion from the sun. For, collect the sun's mean motion from the node (which is the same as his distance gone from it) for the beginning of any gives *year*, and subtract it from 12 signs; then, from the remainder, subtract the next less mean motions belonging to whatever *month* you find them in the table; and from their remainder subtract the next less mean motion for *days*, and so on for *hours* and *minutes:* the result of all which will shew the time of the sun's mean conjunction with the *ascending node* of the moon's orbit.

EXAMPLE VII.

Required the time of the sun's conjunction with the ascending node in the year 1764?

	Sun from node. s	°	′	″
To the year after *Christ's* birth 1753	1	28	0	10
Add complete years 11	7	2	3	56
Mean dist. at beginning of A.D. 1764	9	0	4	15
Subtract this distance from a circle, or	12	0	0	0
And there remains	2	29	55	45
Next less mean motion for March, subtract	2	1	16	39
And the remainder will be	0	28	39	6
Next less mean motion for 27 days, subtract	0	28	2	32
And there remains	0	0	36	34
Next less mean motion for 14 hours, subtracted	0	0	36	21
(Remains nearly) the mean motion of 6 minutes	0	0	0	13

Hence it appears, that the sun will pass by the moon's *ascending node* on the 27th of March, at 14 hours 5 minutes past noon; viz. on the 28th day, at 5 minutes past II in the morning, according to the tables: but this being in a leap-year, and after February, the time is one day too late. Consequently, the true time is at 5 min. past II in the morning on the 27th day; at which time, the descending node will be directly opposite to the sun.

If 6 signs be added [illegible] e remainder arising from the first subtraction, (viz [illegible] 12 signs) and then the work carried on as in the [illegible] example, the result will give the mean time of [illegible] conjunction with the descending node.

[illegible]PLE VIII.

To find when the sun will be in conjunction with the descending node *in the year* 1764?

		Sun from node. s	°	′	″
To the year after *Christ's* birth	1753	1	28	0	19
Add complete years	11	7	2	3	56
M. d. fr. asc. n. at beg. of . .	1764	9	0	4	15
Subtract this distance from a circle, or		12	0	0	0
And the remainder will be		2	29	55	45
To which add half a circle, or . . .		6	0	0	0
And the sum will be		8	29	55	45
Next less mean motion for Sept. subt.		8	12	22	40
And there remains		0	17	22	56

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Next less mean motion for 16 days subtract	0	16	37	4
And the remainder will be	0	0	55	52
Next less mean motion for 21 hours, subtract	0	0	54	32
Remainder (nearly) the mean motion of 31 minutes	0	0	1	20

So that, according to the tables, the sun will be in conjunction with the *descending node* on the 16 of September, at 21 hours 31 minutes past noon: one day later than the truth, on account of the leap-year.

The limit of *eclipses*

When the moon changes within 18 days before or after the sun's conjunction with either of the nodes, the sun will be eclipsed at that change: and when the moon is full within 12 days before or after the time of the sun's conjunction with either of the nodes, she will be eclipsed at that full: otherwise not.

Their period and restitution.

If to the mean time of any eclipse, either of the sun or moon, we add 557 Julian years 21 days 18 hours 11 minutes and 51 seconds (in which there are exactly 6890 mean lunations) we shall have the mean time of another eclipse. For at the end of that time, the moon will be either new or full, according as we add it to the time of new or full moon; and the sun will be only 45″ farther from the same node, at the end of the said time, than he was at the beginning of it; as appears by the following example.[128]

Note 128. Dr. HALLEY's period of eclipses contains only 18 years 11 days 7 hours 43 minutes 20 seconds; in which time, according to his tables, there are just 223 mean lunations: but, as in that time, the sun's mean motion from the node is no more than 11s 29° 31′ 49″, which wants 8′ 21l″ of being as nearly in conjunction with the same node at the end of the period as it was at the beginning; this period cannot be of constant duration for finding eclipses, because it will in time fall quite without their limits. The following tables make this period 31 seconds shorter, as appears by the following calculation.

LECT. XII.

The period.		Moon fr. sun.				Sun fr. node.			
		s	°	′	″	s	°	′	″
Complete years	500	3	5	32	47	10	14	45	8
	40	8	26	50	37	1	23	58	49
	17	3	2	21	39	10	28	40	55
days	21	8	16	0	21	0	21	48	38
hours	18	0	9	8	34	0	0	46	44
minutes	11	0	0	5	35	0	0	0	29
seconds	51	0	0	0	26	0	0	0	0
Mean motions		0	0	0	0	0	0	0	45

And this period is so very near, that in 6000 years it will vary no more from the truth, as to the restitution of eclipses, than 8 minutes of a degree; which may be reckoned next to nothing. It is the shortest in which, after many trials, I can find so near a conjunction of the sun, moon, and the same node.

The period.		Moon fr. Sun.				Sun fr. node.			
		s	°		″	s	°	′	″
Complete years	18	7	11	59	4	11	17	46	16
days	11	4	14	5	54		11	26	20
hours	7		8	33	20			18	11
min.	42			21	20			1	49
sec.	44				52				2
Mean motions		0	0	0	0	11	29	31	49

Note by the Author.

This Table is made by the continual addition of a mean lunation, viz. 29^{d} 12^{h} 44^{m} 3^{s} 6th 21^{iv} 14^{v} 24^{vi} 0^{vii}

LECT. XII.

LUN.		DAYS.	H.	M.	S.	TH.
[illegible]	Contain	29	12	44	3	6
2		59	1	28	6	13
3		88	14	12	9	19
5		118	2	50	12	25
[illegible]		147	15	40	15	32
6		177	4	24	18	38
7		206	17	8	21	44
8		236	5	52	24	51
9		265	18	36	27	57
10		295	7	20	31	3
20		590	14	41	2	7
30		885	22	1	33	11
40		1181	5	22	4	14
[illegible]		1476	12	42	35	18
100		2953	1	25	10	35
200		5906	2	50	21	11
300		8859	4	15	31	46
[illegible]		11812	5	40	42	22
500		14765	7	5	52	57
1000		29530	14	11	45	54
2000		59061	4	23	31	48
3000		88591	18	35	17	42
4000		118122	8	47	3	36
5000		147652	22	58	49	30
[illegible]		295305	21	57	39	0
20000		590611	19	55	18	0
30000		885917	17	52	57	0
40000		1181223	15	50	36	0
50000		1476529	13	48	15	0
100000		2953059	3	36	30	0

In 100000 mean lunations, there are 8085 Julian years 12 days 21 hours 36 minutes 30 seconds = 2953059 days 3 hours 36 minutes 30 seconds.

PROOF OF THE TABLE.

	In	Moon from sun. s	°	′	″
Julian years.	4000	1	14	22	12
	4000	1	14	22	12
	80	5	23	41	15
	5	10	0	18	28
Days	12	4	26	17	20
Hours	21	0	10	40	1
Min.	36	0	0	18	17
Sec.	30	0	0	0	15
M. fr. sun.		0	0	0	0

Having by the former precepts computed the mean time of new moon in January, for any given year, it is easy, by this Table, to find the mean time of new moon in January for any number of years afterward: and by means of a small table of lunations for 12 or 13 months, to make a general table for finding the mean time of new or full moon in any given year and month whatever.

	D.	H.	M.	S.	TH.
In 11 lunations there are . . .	324	20	4	34	10.
In 12 lunations there are . . .	354	8	48	37	16.
In 13 lunations there are . . .	383	21	32	40	23.

But then it would be best to begin the year with March, to avoid the inconvenience of losing a day by mistake in leap year.

A Table of the Moon's mean Motion from the Sun.

Years of the Julian period.	Years of the World.	Yrs. before and after CHRIST.	Moon from sun. s	°	′	″
706	0	4008	6	28	1	17
714	8	4000	5	9	23	24
1714	[redacted]	3000	11	20	28	57
2714	2008	2000	6	1	34	30
3714	3008	1000	0	12	40	3
3814	3108	900	10	19	46	36
3914	3208	800	8	26	53	9
4014	3308	700	7	3	59	43
4114	3408	600	5	11	6	16
4214	3508	500	3	18	12	49
4314	3608	400	1	25	19	23
4414	3708	300	0	2	25	56
4514	3808	200	10	9	32	29
4614	3908	100	8	16	39	3
4714	4008	1	6	23	45	36
4814	4108	101	5	0	52	9
4914	4208	201	3	7	58	43
5014	4308	301	1	15	5	16
5114	4408	401	11	22	11	49
5214	4508	501	9	29	18	23
5714	5008	1001	1	4	51	9
6414	5708	1701	0	24	37	2
6466	5760	1753	10	9	24	56
6514	5808	1801	6	6	26	16

Before the year of CHRIST 1.—After CHRIST.

Complete years.	Moon from sun. s	°	′	″
11	0	10	14	20
12	5	2	3	11
13	9	11	40	35
14	1	21	18	0
15	6	0	55	24
[redacted]	10	22	44	15
17	3	2	21	39
18	7	11	59	4
19	11	21	36	27
20	4	13	25	19
40	8	26	50	37
60	1	10	15	56
80	5	23	41	15
100	10	7	6	33
200	8	14	13	7
300	6	21	19	40
400	4	28	26	13
500	3	5	32	47
[redacted]	6	11	5	33
2000	0	22	11	6
3000	7	3	16	39
4000	1	14	22	12

Months.	Moon from sun. s	°	′	″
Jan.	0	0	0	0
Feb.	0	17	54	48
Mar.	11	29	15	16
April	0	17	10	3
May	0	22	53	23
June	1	10	48	11
July	1	16	31	32
Aug.	2	4	26	20
Sept.	2	22	21	8
Oct.	2	28	4	29
Nov.	3	15	59	17
Dec.	3	21	49	7

Complete years.	Moon from sun. s	°	′	″
1	4	9	37	34
2	8	19	14	46
3	0	28	52	13
4	5	20	41	4
5	10	0	18	28
6	2	9	55	52
7	6	19	33	17
8	11	11	22	7
9	3	20	59	32
10	8	0	36	56

Julian years, three of which have 365 days, and the fourth 366.

The 4008th year before the year of CHRIST 1, was the 4007th year before the year of his birth; and is supposed to have been the year of the creation.

This Table agrees with the the *old stile* until the year 1753; and after that, with the *new*.

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A Table of the Moon's mean Motion from the Sun.

Days	Moon from sun. s	°	′	″
1	0	12	11	27
2	0	24	22	53
3	1	6	34	20
4	1	18	45	47
[illegible]	2	0	57	13
6	2	13	8	40
7	2	25	20	7
8	3	7	31	34
[illegible]	3	19	43	0
10	4	1	54	27
11	4	14	5	54
12	4	26	17	20
13	5	8	28	47
[illegible]	5	20	40	14
15	6	2	51	40
16	6	15	3	7
17	6	27	14	34
[illegible]	7	9	26	0
19	7	21	37	27
20	8	3	48	54
21	8	16	0	21
22	8	28	11	47
23	9	10	23	14
24	9	22	34	41
25	10	4	46	7
26	10	16	57	34
27	10	29	9	1
28	11	11	20	27
[illegible]	11	23	31	54
30	0	5	43	21
31	0	17	54	47
32	1	0	6	15

H. M. S.	Moon from sun. ° ′ ″	′ ″ ‴	″ ‴ ⁗
1	0	30	29
2	1	0	57
3	1	31	26
4	2	1	54
5	2	32	23
6	3	2	52
7	3	33	20
8	4	3	49
9	4	34	18
10	5	4	46
11	5	35	15
12	6	5	43
13	6	36	12
14	7	6	41
15	7	37	9
16	8	7	38
17	8	38	6
18	9	8	35
19	9	39	4
20	10	9	32
21	10	40	1
22	11	10	30
23	11	40	58
24	12	11	27
25	12	41	55
26	13	12	24
27	13	42	53
28	14	13	21
29	14	43	50
30	15	14	18

M. S. TH.	Moon from sun. ′ ″ ‴	″ ‴ ⁗	‴ ⁗ v
31	15	44	47
32	16	15	16
33	16	45	44
34	17	16	13
35	17	46	42
36	18	17	10
37	18	47	39
38	19	18	7
39	19	48	36
40	20	19	5
41	20	49	33
42	21	20	2
43	21	50	31
44	22	20	59
45	22	51	28
[illegible]	23	21	56
47	23	52	25
48	24	22	54
49	24	53	22
50	25	23	51
51	25	54	19
52	26	24	48
[illegible]	26	55	17
54	27	25	45
55	27	56	14
56	28	26	43
57	28	57	11
58	29	27	40
59	29	58	8
60	30	28	37

1 Lunation = 29d 12h 44m 3s 6th 21iv 14v 24vi 0vii

In leap years, after February, a day and its motion must be added to the time for which the moon's mean distance from the sun is given. But, when the mean time of any new or full moon is required in leap-year after February, a day must be subtracted from the mean time thereof, as found by the tables. In common years they give the day right.

A Table of the Sun's mean Motion from the Moon's Ascending Node.

Years of the Julian period.	Years of the World.	Yrs. before and after CHRIST.	Sun from node. s	°	′	″
700	0	4008	7	6	17	9
714	8	4000	0	11	4	55
1714	1008	3000	9	10	35	11
2714	2008	2000	6	10	5	28
3714	3008	1000	3	9	35	44
3814	3108	900	7	24	32	46
3914	3208	800	0	9	29	48
4014	3308	700	4	24	26	49
4114	3408	600	9	9	23	51
4214	3508	500	1	24	20	53
4314	3608	400	6	9	17	54
4414	3708	300	10	24	14	56
4514	3808	200	3	9	11	58
4614	3908	100	7	24	8	59
4714	4008	1	0	9	6	1
4814	4108	101	4	24	3	3
4914	4208	201	9	9	0	4
5014	4308	301	1	23	57	6
5114	4408	401	6	8	54	8
5214	4508	501	10	23	51	9
5714	5008	1001	9	8	36	18
6414	5708	1701	4	23	15	30
6466	[illegible]	1753	1	28	0	19
6514	5808	1801	8	25	44	44

Before the year of CHRIST 1. — After CHRIST.

Complete years.	Sun from node. s	°	′	″
11	7	2	3	56
12	7	22	11	39
13	8	11	17	2
14	9	0	22	25
15	9	19	27	49
16	10	9	35	31
17	10	28	40	55
18	11	17	46	18
[illegible]	0	6	51	43
20	0	26	59	24
40	1	23	58	49
60	2	20	58	13
80	3	17	57	37
[illegible]	4	14	57	2
200	8	29	54	3
[illegible]	1	14	51	5
400	5	29	48	7
500	10	14	45	8
1000	3	29	30	17
2000	5	29	0	33
3000	2	28	30	50
4000	11	28	1	6

Months	Sun from node s	°	′	″
Jan.	0	0	0	0
Feb.	1	2	11	48
Mar.	2	1	16	39
April	3	3	28	27
May	4	4	37	57
June	5	6	49	45
July	6	7	59	14
Aug.	7	9	11	1
Sept.	8	12	22	49
Oct.	9	13	32	18
Nov.	10	15	44	6
Dec.	11	16	53	34

The 4008th year before the year of CHRIST 1, was the 4007th year before the year of his birth; and is supposed to have been [illegible] year of the creation.

Complete years.	Sun from node. s	°	′	″
1	0	19	6	23
2	1	8	10	47
3	1	27	16	10
4	2	17	23	53
5	3	6	29	16
6	3	25	34	40
7	4	14	40	3
8	5	4	47	46
9	5	23	53	9
10	6	12	58	53

Julian years, three of which have 365 days, and the fourth 366.

This Table agrees with the the *old stile* until the year 1753; and after that, with the new.

A Table of the Sun's mean Motion from the Moon's Ascending Node.

Days.	Sun from node. s ° ' "	H. M. S.	Sun from node. ° ' "	M. S. TH.	Sun from node. ' " '''
1	0 1 2 19	1	0 2 26	31	1 20 31
2	0 2 4 38	2	0 5 12	32	1 23 7
3	0 3 6 57	3	0 7 48	33	1 25 43
4	0 4 9 16	4	0 10 23	[illegible]	1 28 9
5	0 5 11 36	5	0 12 59	35	1 31 55
6	0 6 13 54	6	0 15 35	[illegible]	1 33 31
7	0 7 16 13	7	0 18 11	37	1 36 6
8	0 8 18 32	[illegible]	0 20 47	[illegible]	1 38 42
9	0 9 20 51	9	0 23 23	39	1 41 18
10	0 10 23 10	10	0 25 58	40	1 43 54
11	0 11 25 29	11	0 28 33	41	1 46 30
[illegible]	0 12 27 48	12	0 31 9	42	1 49 5
13	0 13 30 7	13	0 33 45	43	1 51 41
[illegible]	0 14 32 26	14	0 36 21	[illegible]	1 54 17
15	0 15 34 45	15	0 38 57	45	1 56 53
16	0 16 37 4	16	0 41 32	46	1 59 29
17	0 17 39 23	17	0 44 8	47	2 2 5
18	0 18 41 41	18	0 46 44	[illegible]	2 4 41
[illegible]	0 19 44 0	19	0 49 20	[illegible]	2 7 17
20	0 20 46 19	20	0 51 56	50	2 9 53
21	0 21 48 38	[illegible]	0 54 32	51	2 12 29
22	0 22 50 57	22	0 57 8	[illegible]	2 15 5
23	0 23 53 16	23	0 59 43	53	2 17 41
[illegible]	0 24 55 35	24	1 2 19	54	2 20 17
25	0 25 57 54	25	1 4 55	55	2 22 53
26	0 27 0 13	[illegible]	1 7 31	56	2 25 29
27	0 28 2 32	[illegible]	1 10 7	57	2 28 4
28	0 29 4 51	28	1 12 43	58	2 30 40
29	1 0 7 10	29	1 15 9	59	2 33 16
30	1 1 9 29	30	1 17 55	60	2 35 52
31	1 1 11 48				
32	1 3 14 7				

In leap years, after February, add one day and one day's motion to the time at which the sun's mean distance from the ascending node is required.

SUPPLEMENT

The Description of a new and safe Crane, which has four different Powers, adapted to different Weights.

The common crane consists only of a large wheel and axle; and the rope, by which goods are drawn up from ships, or let down from the quay to them, winds or coils round by the axle, as the axle is turned by men walking in the wheel. But, as these engines have nothing to stop the weight from running down, if any of the men happen to trip or fall in the wheel, the weight descends, and turns the wheel rapidly backward, and tosses the men violently about within it; which has produced melancholy instances, not only of limbs broken, but even of lives lost, by this ill-judged construction of cranes. And besides, they have but one power for all sorts of weights; so that they generally spend as much time in raising a small weight as in raising a great one.

These imperfections and dangers induced me to think of a method of remedying them. And for that purpose, I contrived a crane with a proper stop to prevent the danger, and with different powers suited to different weights; so that there might be as little loss of time as possible: and also, that when heavy goods are let down into ships, the descent may be regular and deliberate.

This crane has four different powers: and, I believe,

it might be built in a room eight feet in width: the gib being on the outside of the room.

Three trundles, with different numbers of staves, are applied to the cogs of a horizontal wheel with an upright axle; and the rope, that draws up the weight, coils round the axle. The wheel has 96 cogs, the largest trundle 24 staves, the next largest has 12, and the smallest has 6. So that the largest trundle makes 4 revolutions for one revolution of the wheel; the next makes 8, and the smallest makes 16. A winch is occasionally put upon the axis of either of these trundles, for turning it; the trundle being then used that gives a power best suited to the weight: and the handle of the winch describes a circle in every revolution equal to twice the circumference of the axle of the wheel. So that the length of the winch doubles the power gained by each trundle.

As the power gained by any machine, or engine whatever, is in direct proportion as the velocity of the power is to the velocity of the weight; the powers of this crane are easily estimated, and they are as follows.

If the winch be put upon the axle of the largest trundle, and turned four times round, the wheel and axle will be turned once round: and the circle described by the power that turns the winch, being, in each revolution, double the circumference of the axle, when the thickness of the rope is added thereto; the power goes through eight times as much space as the weight rises through: and therefore (making some allowance for friction) a man would raise eight times as much weight by the crane as he would by his natural strength without it: the power, in this case, being as eight to one.

If the winch be put upon the axis of the next trundle, the power will be as sixteen to one, because it moves 16 times as fast as the weight moves.

If the winch be put upon the axis of the smallest

trundle, and turned round; the power will be as 32 to one.

But, if the weight should be too great, even for this power to raise, the power may be doubled by drawing up the weight by one of the parts of a double rope, going under a pulley in the moveable block, which is hooked to the weight below the arm of the gib; and then the power will be as 64 to one. That is, a man could then raise 64 times as much weight by the crane as he could raise by his natural strength without it; because for every inch that the weight rises, the working power will move through 64 inches.

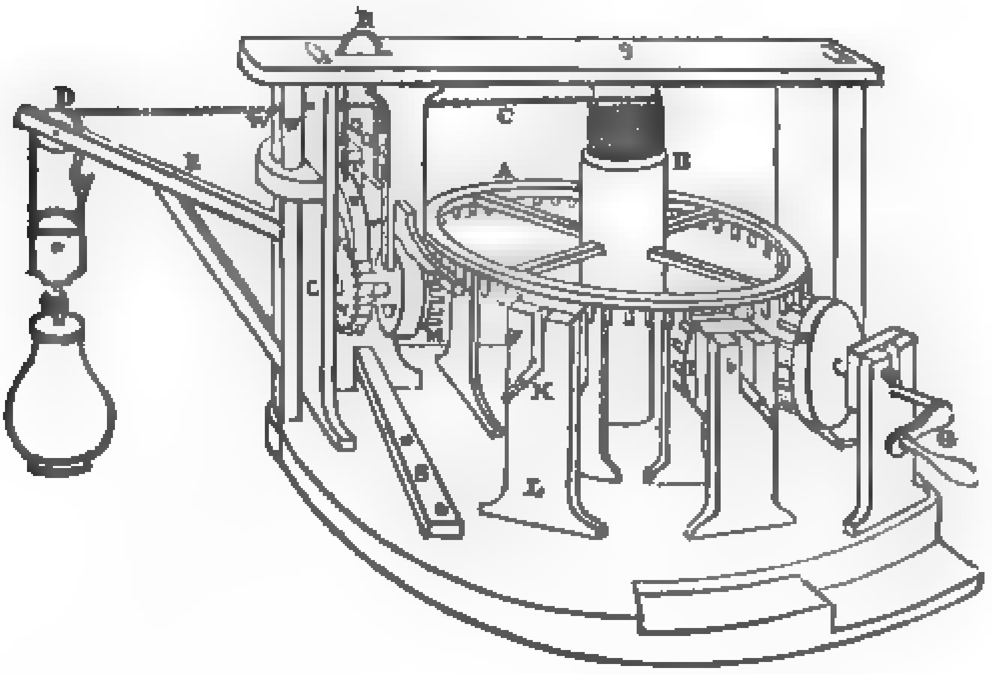
By hanging a block with two pullies to the arm of the gib, and having two pullies in the moveable block that rises with the weight, the rope being doubled over and under these pullies, the power of the crane will be as 128 to one. And so, by increasing the number of pullies, the power may be increased as much as you please: always remembering, that the larger the pullies are, the less is their friction.

Whilst the weight is drawing up, the ratch-teeth of a wheel slip round below a catch or click that falls successively into them, and so hinders the crane from turning backward, and detains the weight in any part of its ascent, if the man who works at the winch should accidentally happen to quit his hold, or choose to rest himself before the weight be quite drawn up.

In order to let down the weight, a man pulls down one end of a lever of the second kind, which lifts the catch of the ratchet-wheel, and gives the weight liberty to descend. But, if the descent be too quick, he pulls the lever a little farther down, so as to make it rub against the outer edge of a round wheel; by which means he lets down the weight as slowly as he pleases: and, by pulling a little harder, he may stop the weight, if needful, in any part of its descent. If he accidentally

quits hold of the lever, the catch immediately falls, and stops both the weight and the whole machine.

This crane is represented thus: where *A* is the great



wheel, and *B* its axle on which the rope *C* winds. This rope goes over a pulley *D* in the end of the arm of the gib *E*, and draws up the weight *F*, as the winch *G* is turned round. *H* is the largest trundle, *I* the next, and *K* is the axis of the smallest trundle, which is supposed to be hid from view by the upright supporter *L*. A trundle *M* is turned by the great wheel, and on the axis of this trundle is fixed the rachet-wheel *N*, into the teeth of which the catch *O* falls. *P* is the lever, from which goes a rope *Q Q*, over a pulley *R* to the catch; one end of the rope being fixed to the lever, and the other end to the catch. *S* is an elastic bar of wood, one end of which is screwed to the floor: and, from the other end goes a rope (out of sight in the figure) to the further end of the lever, beyond the pin or axis on which it turns in the upright supporter *T*. The use of this bar is to keep up the lever from rubbing against the edge of the wheel *U*, and to let the catch keep in the

teeth of the ratchet-wheel: But a weight hung to the farther end of the lever would do full as well as the elastic bar and rope.

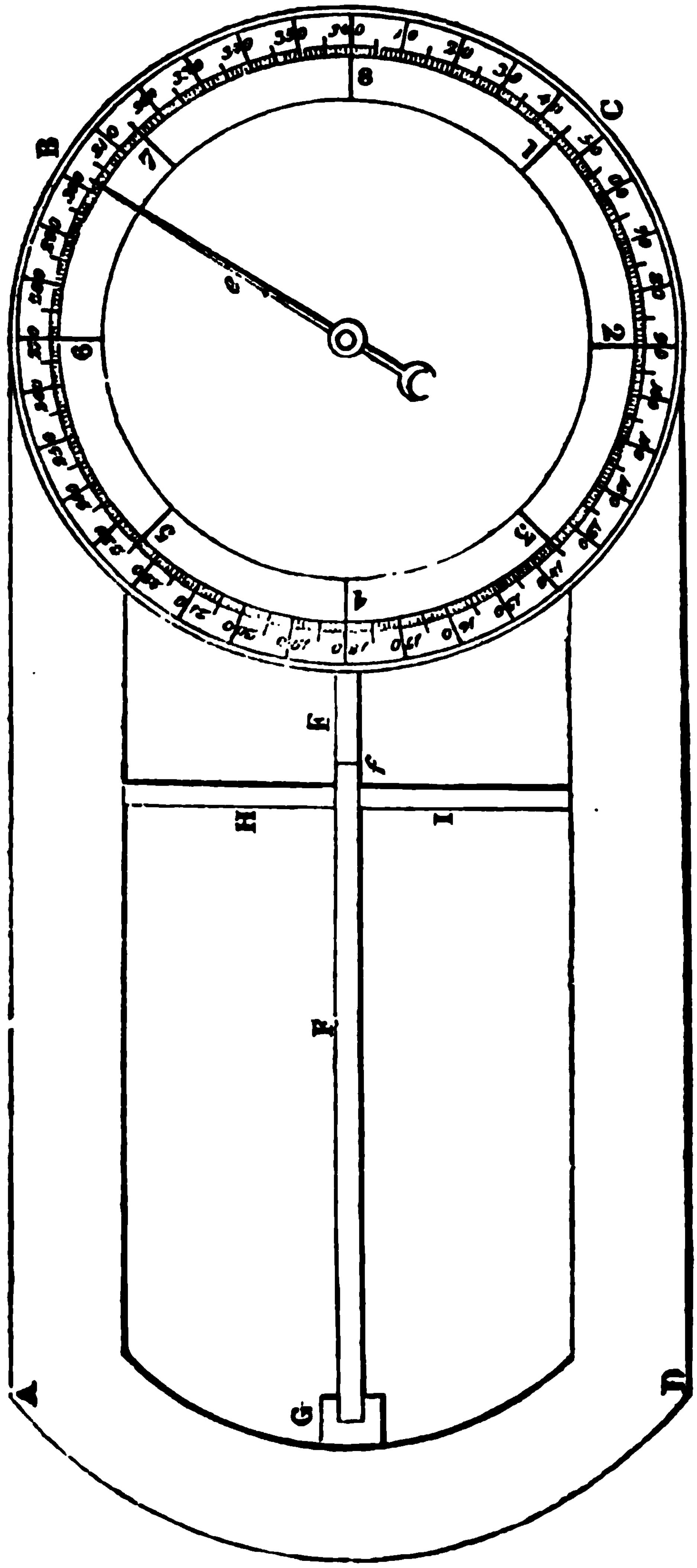
When the lever is pulled down, it lifts the catch out of the ratchet-wheel, by means of the rope *Q Q*, and gives the weight *F* liberty to descend: but if the lever *P* be pulled a little farther down than what is sufficient to lift the catch *O* out of the rachet-wheel *N*, it will rub against the edge of the wheel *U*, and thereby hinder the too quick descent of the weight; and will quite stop the weight if pulled hard. And if the man who pulls the lever, should happen inadvertently to let it go; the elastic bar will suddenly pull it up, and the catch will fall down and stop the machine.

W W are two upright rollers above the axis or upper gudgeon of the gib *E*: their use is to let the rope *C* bend upon them, as the gib is turned to either side, in order to bring the weight over the place where it is intended to be let down.

N. B. The rollers ought to be so placed, that if the rope *C* be stretched close by their utmost sides, the half thickness of the rope may be perpendicularly over the center of the upper gudgeon of the gib. For then, and in no other position of the rollers, the length of the rope between the pulley in the gib and the axle of the great wheel will be always the same, in all positions of the gib: and the gib will remain in any position to which it is turned.

When either of the trundles is not turned by the winch in working the crane, it may be drawn off from the wheel, after the pin near the axis of the trundle is drawn out, and the thick piece of wood is raised a little behind the outward supporter of the axis of the trundle. But this is not material; for, as the trundle has no friction on its axis but what is occasioned by its weight, it will be turned by the wheel without any sensible resistance in working the crane.

A Pyrometer, that makes the Expansion of Metals by Heat visible to the five and forty thousandth Part of an inch.



The upper surface of this machine is thus represented: Its frame *A B C D* is made of mahogany wood, on which is a circle divided into 360 equal parts; and within that circle is another, divided into 8 equal parts. If the short bar *E* be pushed one inch forward (or toward the center of the circle) the index *e* will be turned 125 times round the circle of 360 parts or degrees. As 125 times 360 is 45,000, it is evident, that if the bar *E* be moved only the 45,000dth part of an inch, the index will move one degree of the circle. But as in my pyrometer, the circle is 9 inches in diameter, the motion of the index is visible to half a degree, which answers to the ninety thousandth part of an inch in the motion or pushing of the short bar *E*.

One end of a long bar of metal *F* is laid into a hollow place in a piece of iron *G*, which is fixed to the frame of the machine: and the other end of this bar is laid against the end of the short bar *E*, over the supporting cross bar *H I*: and, as the end *f* of the long bar is placed close against the end of the short bar, it is plain, that if *F* expands, it will push *E* forward, and turn the index *e*.

The machine stands on four short pillars, high enough from a table, to let a spirit-lamp be put on the table under the bar *F*; and when that is done, the heat of the flame of the lamp expands the bar, and turns the index.

There are bars of different metals, as silver, brass, and iron: all of the same length as the bar *F*, for trying experiments on the different expansion of different metals, by equal degrees of heat applied to them for equal lengths of time: which may be measured by a pendulum, that swings seconds. Thus,

Put on the brass bar *F*, and set the index to the 360th degree: then put the lighted lamp under the bar, and count the number of seconds in which the index goes

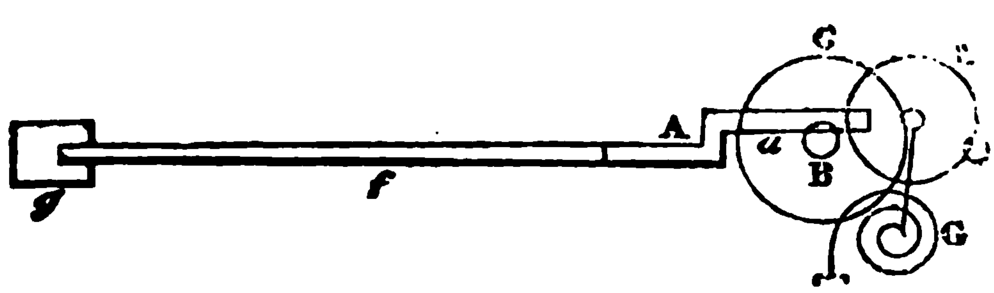
round the plate, from 360 to 360 again; and then blow out the lamp, and take away the bar.

This done, put on an iron-bar *F* where the brass one was before, and then set the index to the 360th degree again. Light the lamp, and put it under the iron-bar, and let it remain just as many seconds as it did under the brass one; and then blow it out, and you will see how many degrees the index has moved in the circle: and by that means you will know in what proportion the expansion of iron is to the expansion of brass; which I find to be as 210 is to 360, or as 7 is to 12.—By this method, the relative expansion of different metals may be found.

The bars ought to be exactly of equal size; and to have them so, they should be drawn, like wire, through a hole.

When the lamp is blown out, you will see the index turn backward; which shews that the metal contracts as it cools.

The inside of this pyrometer is constructed as follows



A a is the short bar, which moves between rollers; and, on the side *a* it has 15 teeth in an inch, which take into the leaves of a pinion *B* (12 in number) on whose axis is the wheel *C* of 100 teeth, which take into the 10 leaves of the pinion *D*, on whose axis is the wheel *E* of 100 teeth, which take into the 10 leaves of the pinion *F*, on the top of whose axis is the index above mentioned.

Now, as the wheels *C* and *E* have 100 teeth each, and the pinions *D* and *F* have ten leaves each; it is plain, that if the wheel *C* turns once round, the pinion *F* and

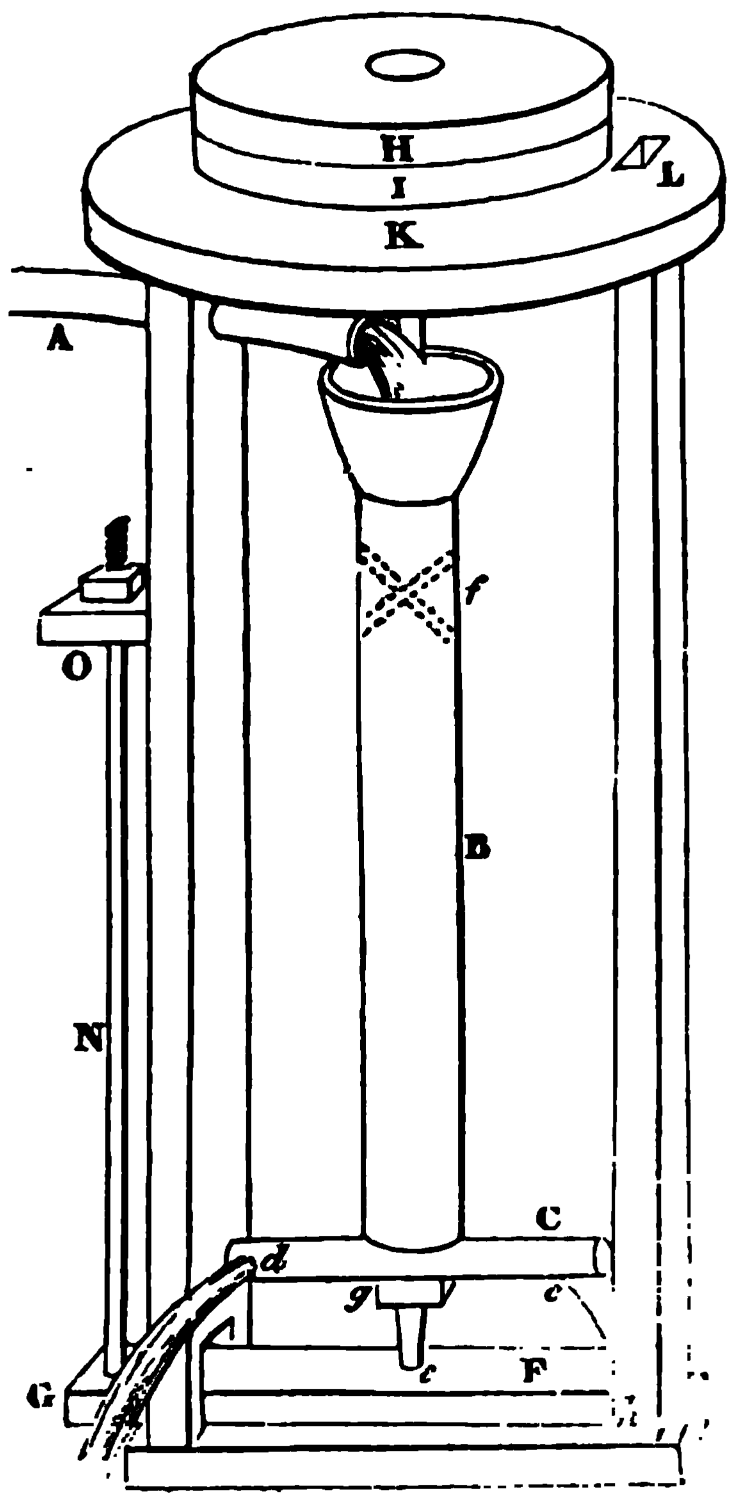
the index on its axis will turn 100 times round. But, as the first pinion *B* has only 12 leaves, and the bar *A a* that turns it has 15 teeth in an inch, which is 12 and a fourth part more; one inch motion of the bar will cause the last pinion *F* to turn a hundred times round, and a fourth part of a hundred over and above, which is 25. So that, if *A a* be pushed one inch, *F* will be turned 125 times round.

A silk thread *b* is tied to the axis of the pinion *D*, and wound several times round it; and the other end of the thread is tied to a piece of slender watch-spring *G* which is fixed into the stud *H*. So that, as the bar *f* expands, and pushes the bar *A a* forward, the thread winds round the axle, and draws out the spring; and as the bar contracts, the spring pulls back the thread, and turns the work the contrary way, which pushes back the short bar *A a* against the long bar *f*. This spring always keeps the teeth of the wheels in contact with the leaves of the pinions, and so prevents any shake in the teeth.

In the former diagram, the eight divisions of the inner circle are so many thousandth parts of an inch in the expansion or contraction of the bars; which is just one thousandth part of an inch for each division moved over by the index.

A Water-mill, invented by Dr. Barker, *that has neither Wheel nor Trundle.*

This machine is represented thus, in which *A* is a pipe or channel that brings water to the upright tube *B*. The water runs down the tube, and thence into the horizontal trunk *C*, and runs out through holes at *d* and *e* near the ends of the trunk on the contrary sides thereof.



The upright spindle *D* is fixed in the bottom of the trunk, and screwed to it below by the nut *g*; and is fixed into the trunk by two cross bars at *f*: so that, if the tube *B* and trunk *C* be turned round, the spindle *D* will be turned also.

The top of the spindle goes square into the rynd of the upper mill-stone *H*, as in common mills; and, as the trunk, tube, and spindle turn round, the mill-stone is turned round thereby. The lower, or quiescent mill-stone is represented by *I*; and *K* is the floor on which it rests, and wherein is the hole *L* for letting the meal run through, and fall down into a trough which may be about *M*.

The hoop or case that goes round the mill-stone rests on the floor *K*, and supports the hopper, in the common way. The lower end of the spindle turns in a hole in the bridge-tree *G F*, which supports the mill-stone, tube, spindle, and trunk. This tree is moveable on a pin at *h*, and its other end is supported by an iron-rod *N* fixed into it, the top of the rod going through the fixed bracket *O*, and having a screw-nut *o* upon it, above the bracket. By turning this nut forward or backward, the mill-stone is raised or lowered at pleasure.

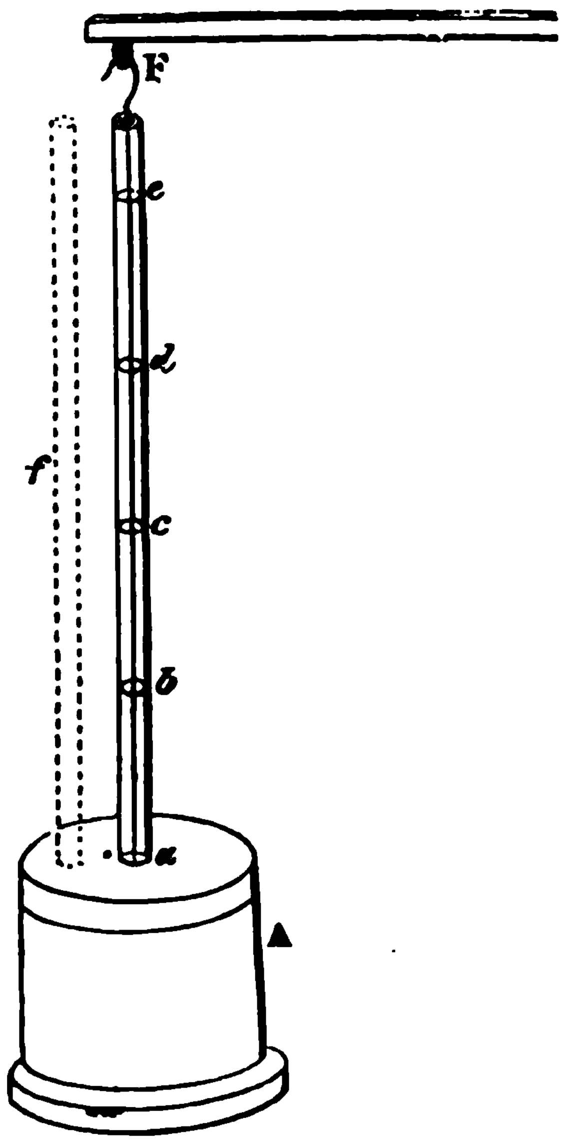
Whilst the tube *B* is kept full of water from the pipe *A*, and the water continues to run out from the ends of the trunk; the upper mill-stone *H*, together with the trunk, tube, and spindle, turns round. But, if the holes in the trunk were stopped, no motion would ensue; even though the tube and trunk were full of water. For,

If there were no hole in the trunk, the pressure of the water would be equal against all parts of its sides within. But, when the water has free egress through the holes, its pressure there is entirely removed: and the pressure against the parts of the sides which are opposite to the holes, turns the machine.[129]

A Machine for demonstrating that, on equal Bottoms, the Pressure of Fluids is in Proportion to their perpendicular Heights, without any regard to their Quantities.

This is termed *The Hydrostatical Paradox;* and the machine for shewing it is represented thus: in which

Note 129. The power of a mill, constructed on this principle, will depend on the height of the column of water allowed to press on the horizontal trunk *c*.



A is a box that holds about a pound of water, *a b c d e* a glass tube fixed in the top of the box, having a small wire within it; one end of the wire being hooked to the end *F* of the beam of a balance, and the other end of the wire fixed to a moveable bottom, on which the water lies, within the box; the bottom and wire being of equal weight with an empty scale (out of sight in the figure) hanging at the other end of the balance. If this scale be pulled down, the bottom will be drawn up within the box, and that motion will cause the water to rise in the glass-tube.

Put one pound weight into the scale, which will move the bottom a little, and cause the water to appear just in the lower end of the tube at *a*; which shews that the water presses with the force of one pound on the bottom: put another pound into the scale, and the water will rise from *a* to *b* in the tube, just twice as high above the bottom as it was when at *a*; and then, as its pressure on the bottom supports two pound weight in the scale, it is plain that the pressure on the bottom is then equal to two pounds. Put a third pound weight in the scale, and the water will be raised from *b* to *c* in the tube, three times as high above the bottom as when it began to appear in the tube at *a*; which shews, that the same quantity of water that pressed, but with the force of one pound on the bottom, when raised no higher than *a*, presses with the force of three pounds

on the bottom when raised three times as high to *c* in the tube. Put a fourth pound weight into the scale, and it will cause the water to rise in the tube from *c* to *d*, four times as high as it was when it was all contained in the box, which shews that its pressure then upon the bottom is four times as great as when it lay all within the box. Put a fifth pound weight into the scale, and the water will rise in the tube from *d* to *e*, five times as high as it was above the bottom before it rose in the tube; which shews that its pressure on the bottom is then equal to five pounds, seeing that it supports so much weight in the scale. And so on, if the tube was still longer; for it would still require an additional pound put into the scale, to raise the water in the tube to an additional height equal to the space *d e;* even if the bore of the tube was so small as only to let the wire move freely within it, and leave room for any water to get around the wire.

Hence we infer, that if a long narrow pipe or tube was fixed in the top of a cask full of liquor, and if as much liquor was poured into the tube as would fill it, even though it were so small as not to hold an ounce weight of liquor : the pressure arising from the liquor in the tube would be as great upon the bottom, and be in as much danger of bursting it out, as if the cask was continued up, in its full size, to the height of the tube, and filled with liquor.

In order to account for this surprising affair, we must consider that fluids press equally in all manner of directions ; and consequently that they press just as strongly upward as they do downward. For, if another tube, as *f*, be put into a hole made into the top of the box, and the box be filled with water ; and then, if water be poured in at the top of the tube *a b c d e*, it will rise in the tube *f* to the same height as it does in the other tube : and if you leave off pouring, when the water is a.

c, or any other place in the tube *a b c d e*, you will find it just as high as the tube *f*: and if you pour in water to fill the first tube, the second will be filled also.

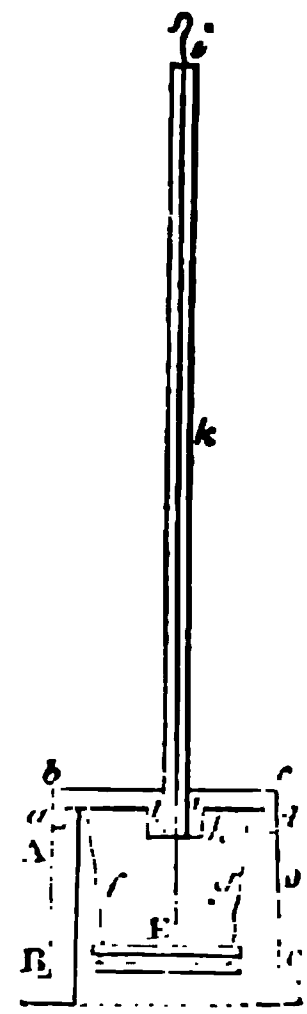
Now it is evident that the water rises in the tube *f*, from the downward pressure of the water in the tube *a b c d e*, on the surface of the water, contiguous to the inside of the top of the box; and as it will stand at equal heights in both tubes, the upward pressure in the tube *f* is equal to the downward pressure in the other tube. But, if the tube *f* were put in any other part of the top of the box, the rising of the water in it would still be the same: or, if the top was full of holes, and a tube put into each of them, the water would rise as high in each tube as it was poured into the tube *a b c d e*; and then the moveable bottom would have the weight of the water in all the tubes to bear, besides the weight of all the water in the box.

And seeing that the water is pressed upward into each tube, it is evident that, if they be all taken away, excepting the tube *a b c d e*, and the holes in which they stood be stopt up; each part, thus stopt, will be pressed as much upward as was equal to the weight of water in each tube. So that, the upward pressure against the inside of the top of the box, on every part equal in breadth to the width of the tube *a b c d e*, will be pressed upward with a force equal to the whole weight of water in the tube. And consequently, the whole upward pressure against the top of the box, arising from the weight or downward pressure of the water in the tube, will be equal to the weight of a column of water of the same height with that in the tube, and of the same thickness as the width of the inside of the box: and this upward pressure against the top will re-act downward against the bottom, and be as great thereon, as would be equal to the weight of a column of water as thick as

the moveable bottom is broad, and as high as the water stands in the tube. And thus, the paradox is solved.

The moveable bottom has no friction against the inside of the box, nor can any water get between it and the box. The method of making it so, is as follows:

A B C D represents a section of the box, and *a b c d* is the lid or top thereof, which goes on tight, like the lid of a common paper snuff box. *E* is the moveable bottom, with a groove around its edge, and it is put into a bladder *f g*, which is tied close around it in the groove by a strong waxed thread; the bladder coming up like a purse within the box, and put over the top of *d* at *a*, and all round, and then the lid pressed on. So that, if water be poured in through the whole *l l* of the lid, it will lie upon the bottom *E*, and be contained in the space *f E g h* within the bladder; and the bottom may be raised by pulling the wire *i*, which is fixed to it at *E*: and by thus pulling the wire, the water will be lifted up in the tube *k*, and as the bottom does not touch against the inside of the box, it moves without friction.



Now, suppose the diameter of this round bottom to be three inches (in which case, the area thereof will be 9 circular inches) and the diameter of the bore of the tube to be a quarter of an inch; the whole area of the bottom will be 144 times as great as the area of the top of a pin that would fill the tube like a cork.

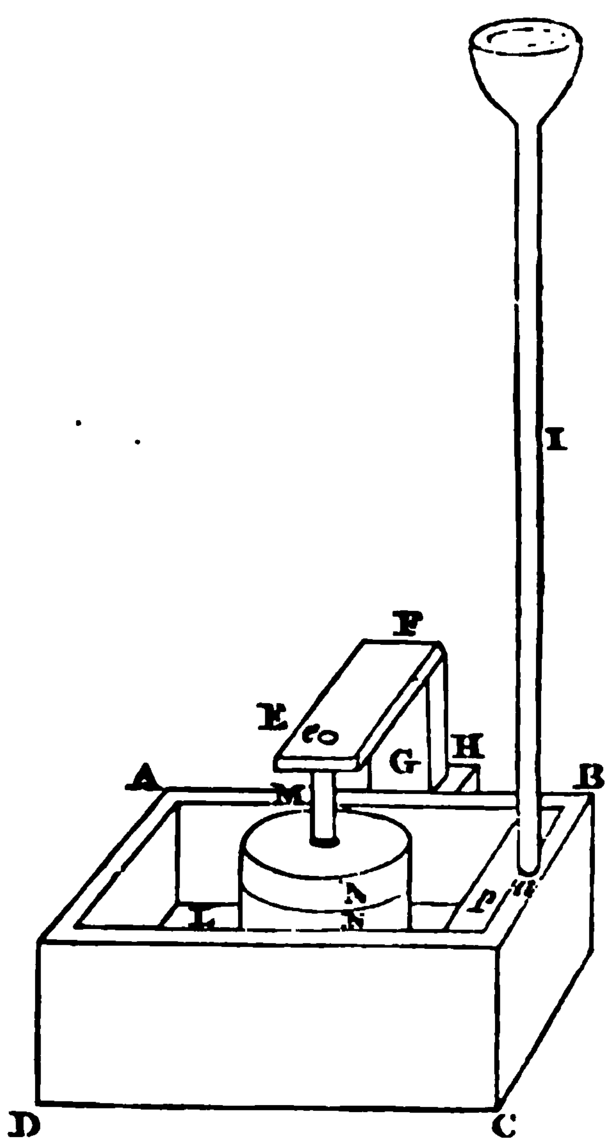
And hence it is plain, that if the moveable bottom be raised only the 144th part of an inch, the water will thereby be raised a whole inch in the tube; and consequently, that if the bottom be raised one inch, it would

raise the water to the top of a tube 144 inches, or 12 feet in height.

N. B. The box must be open below the moveable bottom, to let in the air. Otherwise, the pressure of the atmosphere would be so great upon the moveable bottom if it be three inches in diameter, as to require 108 pounds in the scale, to balance that pressure, before the bottom could begin to move.

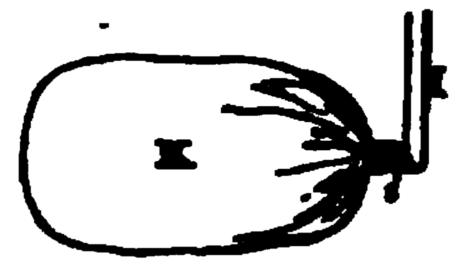
A Machine, to be substituted in place of the common Hydrostatical Bellows.

A B C D is an oblong square box, in one end of which is a round groove, as at *a*, from top to bottom, for receiving the upright glass tube *I*, which is bent to a right angle at the lower end, and to that part is tied the end of a large bladder *K*, which lies in the bottom of the box. Over this bladder is laid the moveable board *L*, in which is fixed an upright wire *M*; and leaden weights, *N N*, to the amount of 16 pounds, with holes in their middle, are put upon the wire, over the board, and press upon it with all their force.



The cross bar *p* is then put on, to secure the tube

from falling, and keep it in an upright position: And then the piece EFG is to be put on, the part G sliding tight into the dove-tailed groove H to keep the weights NN horizontal, and the wire M upright; there being a round hole e in the part EF for receiving the wire.



There are four upright pins in the four corners of the box within, each almost an inch long, for the board L to rest upon; to keep it from pressing the sides of the bladder below it close together at first.

The whole machine being thus put together, pour water into the tube at top; and the water will run down the tube into the bladder below the board; and after the bladder has been filled up to the board, continue pouring water into the tube, and the upward pressure which it will excite in the bladder, will raise the board with all the weight upon it, even though the bore of the tube should be so small, that less than an ounce of water would fill it.

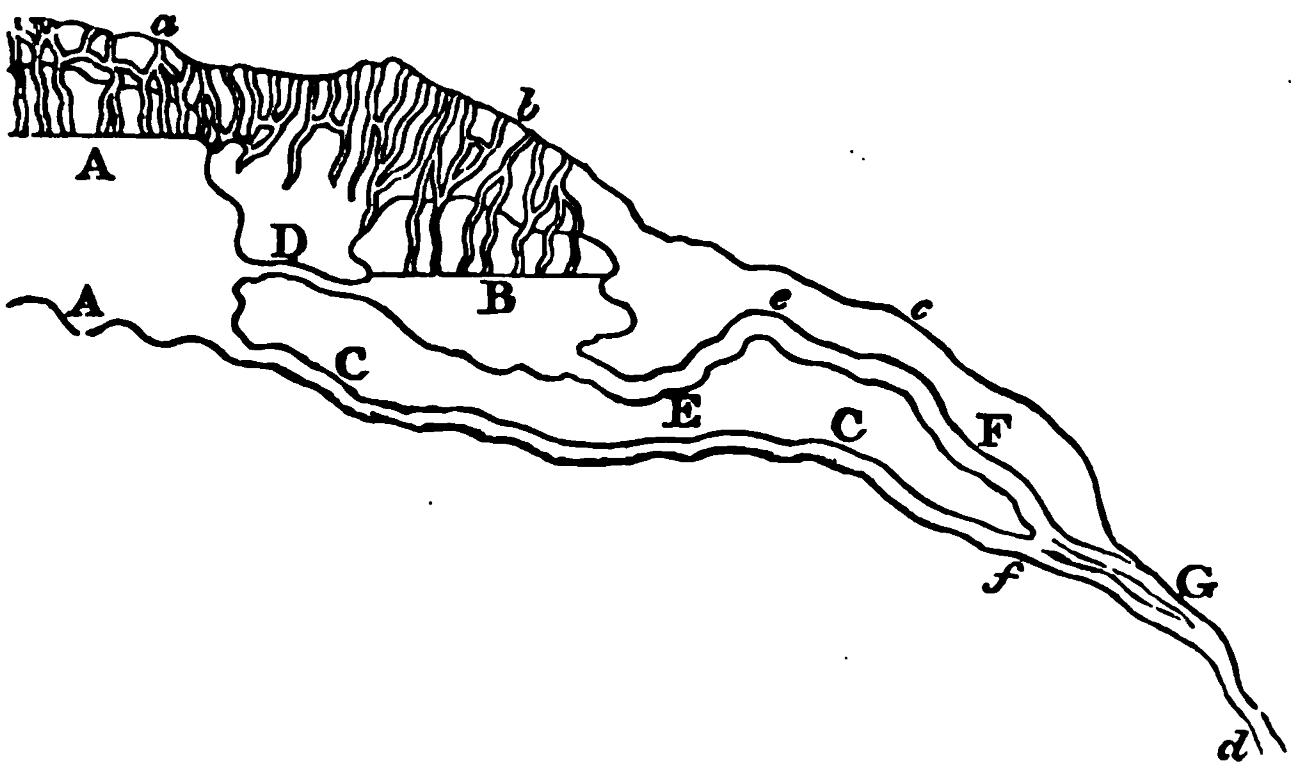
This machine acts upon the same principle, as the one last described, concerning the *Hydrostatical Paradox*. For, the upward pressure against every part of the board (which the bladder touches) equal in area to the area of the bore of the tube, will be pressed upward with a force equal to the weight of the water in the tube; and the sum of all these pressures, against so many areas of the board, will be sufficient to raise it with all the weights upon it.

In my opinion, nothing can exceed this simple machine, in making the upward pressure of fluids evident to sight.[130]

Note 130. The application of this principle in hydrostatics to the construction of a very useful and powerful press, is well worth atten-

The Cause of reciprocating Springs, and of ebbing and flowing Wells, explained.

Let $a\,b\,c\,d$ be a hill, within which is a large cavern $A\,A$ near the top, filled or fed by rains and melted snow on the top a, making their way through chinks



and crannies into the said cavern, from which proceeds a small stream $c\,c$ within the body of the hill, and issues out in a spring at G on the side of the hill, which will run constantly whilst the cavern is fed with water.

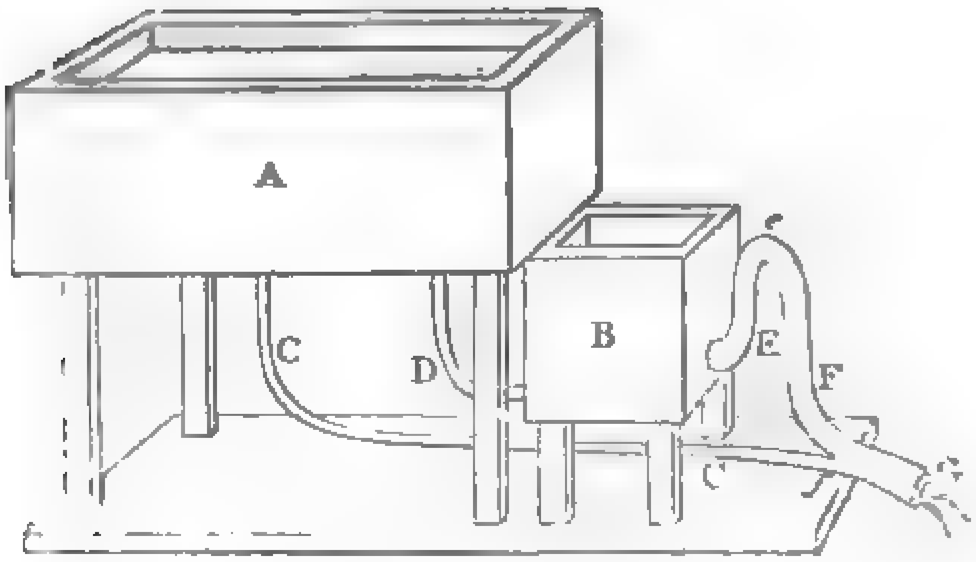
From the same cavern $A\,A$, let there be a small channel D, to carry water into the cavern B; and from that cavern, let there be a bended channel $E\,e\,F$, larger than D, joining with the former channel $c\,c$, as at f before it comes to the side of the hill: and let the joining at f be below the level of the bottom of both these caverns.

As the water rises in the cavern B, it will rise as high

tion. In this apparatus, which was contrived by Mr. Bramah, the water is forced by a small pump into a barrel, in which it acts on a much larger piston; consequently this piston is urged by a force as much greater than that which acts on the first pump-rod, as its surface is greater than that of the small one.

in the channel $E e F$: and when it rises to the top of that channel at e, it will run down the part $e F G$, and make a swell in the spring G, which will continue till all the water is drawn off from the cavern B, by the natural syphon $E e F$, (which carries off the water faster from B, than the channel D brings water to it) and then the swell will stop, and only the small channel $C C$ will carry water to the spring G, till the cavern B is filled to B again by the rill D; and then the water being at the top e of the channel $E e F$, that channel will act again as a syphon, and carry off all the water from B to the spring G, and so make a swelling flow of water at G as before.

To illustrate this by a machine: Let A be a large



wooden box, filled with water; and let a small pipe $C C$ (the upper end of which is fixed into the bottom of the box) carry water from the box to G, where it will run off constantly, like a small spring. Let another small pipe D carry water from the same box to the box or well B, from which let a syphon $E e F$ proceed, and join with the pipe $C C$ at f: the bore of the syphon being larger than the bore of the feeding-pipe D. As the water from this pipe rises in the well B, it will also rise as high in the syphon $E e F$: and when the syphon

is full to the top *e*, the water will run over the bend *e*, down the part *e F*, and go off at the mouth *G*; which will make a great stream at *G*; and that stream will continue, till the syphon has carried off all the water from the well *B*; the syphon carrying off the water faster from *B* than the pipe *D* brings water to it: and then the swell at *G* will cease, and only the water from the small pipe *C C* will run off at *G*, till the pipe *D* fills the well *B* again; and then the syphon will run, and make a swell at *G* as before.

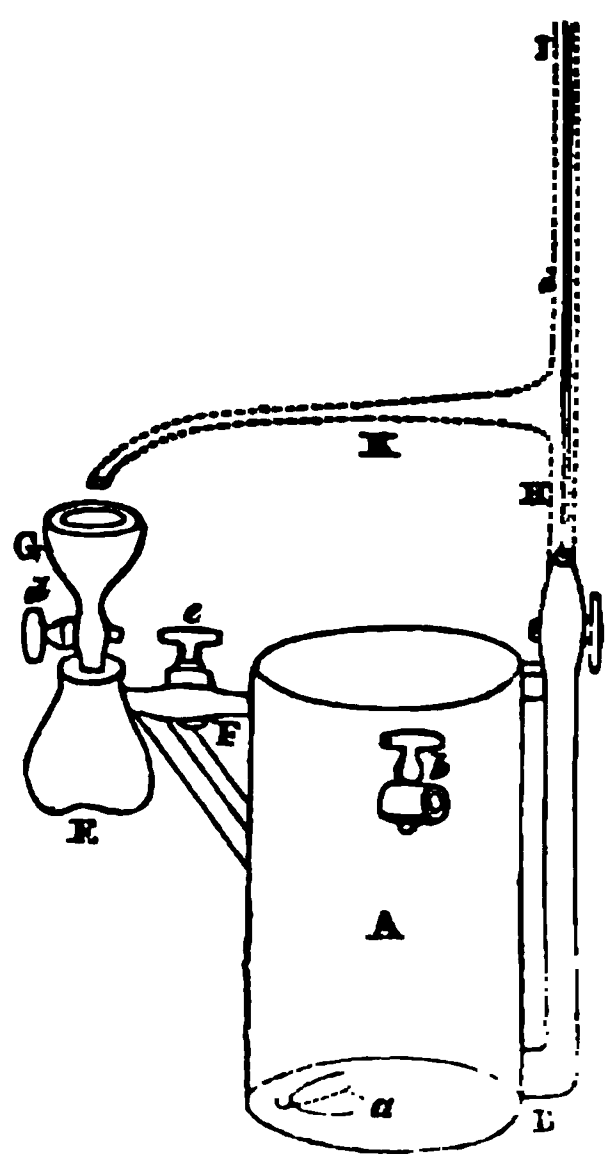
And thus, we have an artificial representation of an ebbing and flowing well, and of a reciprocating spring, in a very natural and simple manner.

An Account of the Principles by which MR. BLAKEY *proposes to raise Water from Mines, or from Rivers to supply Towns and Gentlemen's Seats, by his new-invented Fire-engine, for which he has received* HIS MAJESTY'S *Patent*[131].

Although I am not at liberty to describe the whole of this simple engine, yet I have the Patentee's leave to describe such a one as will shew the principles by which it acts.

Note 131. The subject of the steam-engine has already been very fully examined, in a note to Mr. Ferguson's treatise on Hydrostatics; and the Editor merely inserts the following account of Blakey's engine from a wish to present the Lectures of this valuable Teacher in a perfect form.

Let *A* be a large, strong, close vessel; immersed in water up to the cock *b*, and having a hole in the bottom, with a valve *a* upon it, opening upward within the vessel. A pipe *B C* rises from the bottom of this vessel, and has a cock *c* in it near the top, which is small there, for playing a very high jet *d*. *E* is the little boiler (not so big as a common tea-kettle) which is connected with the vessel *A* by the steam-pipe *F;* and *G* is a funnel, through which a little water must be occasionally poured into the boiler, to yield a proper quantity of steam. And a small quantity of water will do for that purpose, because steam possesses upwards of 14,000 times as much space or bulk as the water does from which it proceeds.[132]



The vessel *A* being immersed in water up to the cock *b*, open that cock, and the water will rush in, through the bottom of the vessel at *a*, and fill it as high up as the water stands on its outside; and the water, coming into the vessel, will drive the air out of it (as high as the water rises within it) through the cock *b*. When the water has done rushing into the vessel, shut

Note 132. Under ordinary circumstances, the bulk of a given quantity of water converted into steam, is not expanded more than two thousand times; but, by encreasing the supply of caloric, the elastic particles may be made to occupy a space infinitely greater.

the cock *b*, and the valve *a* will fall down, and hinder the water from being pushed out that way, by any force that presses on its surface. All the internal part of the vessel above *b*, will be full of common air, when the water rises to *b*.

Shut the cock *c*, and open the cocks *d* and *e*; then pour as much water into the boiler *E* (through the funnel *G*) as will about half fill the boiler; and then shut the cock *d*, and leave the cock *e* open.

This done, make a fire under the boiler *E*, and the heat thereof will raise steam from the water in the boiler; and the steam will make its way thence, through the pipe *F*, into the vessel *A*; and the steam will compress the air (above *b*) with a very great force upon the surface of the water in *A*.

When the top of the vessel *A* feels very hot by the steam under it, open the cock *c* in the pipe *C*; and the air being strongly compressed in *A*, between the steam and the water therein, will drive all the water out of the vessel *A*, up the pipe *B C*, from which it will fly up in a jet to a very great height.—In my fountain, which is made in this manner, after *Mr. Blakey's*, three tea-cupfulls of water in the boiler will afford steam enough to play a jet 30 feet high.

When all the water is out of the vessel *A*, and the compressed air begins to follow the jet, open the cocks *b* and *d* to let the steam out of the boiler *E* and vessel *A*, and shut the cock *e* to prevent any more steam from getting into *A*; and the air will rush into the vessel *A* through the cock *b*, and the water through the valve *a*; and so the vessel will be filled up with water to the cock *b* as before. Then shut the cock *b* and the cocks *c* and *d*, and open the cock *e*; and then, the next steam that rises in the boiler will make its way into the vessel *A* again; and the operation will go on, as above.

When all the water in the boiler *E* is evaporated, and

gone off into steam, pour a little more into the boiler, through the funnel *G*.

In order to make this engine raise water to any gentleman's house; if the house be on the bank of a river, the pipe *B C* may be continued up to the intended height, in the direction *H I*. Or, if the house be on the side or top of a hill, at a distance from the river, the pipe, through which the water is forced up, may be laid along on the hill, from the river or spring to the house.

The boiler may be fed by a small pipe *K*, from the water that rises in the main pipe *B C H I*: the pipe *K* being of a very small bore, so as to fill the funnel *G* with water in the time that the boiler *E* will require a fresh supply. And then, by turning the cock *d*, the water will fall from the funnel into the boiler. The funnel should hold as much water as will about half fill the boiler.

When either of these methods of raising water, perpendicularly or obliquely is used, there will be no occasion for having the cock *c* in the main pipe *B C H I*; for such a cock is requisite only, when the engine is used as a fountain.

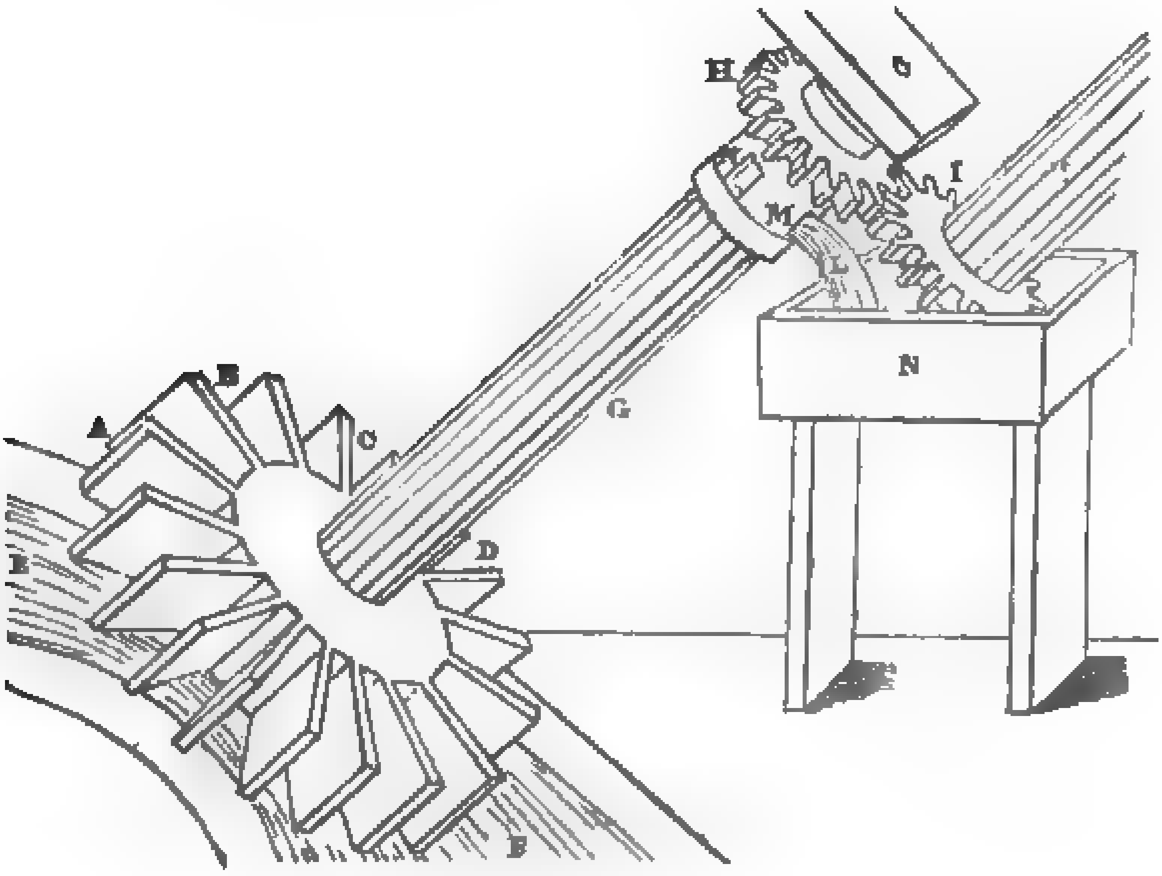
A contrivance may be very easily made, from a lever to the cocks *b*, *d*, and *e*; so that, by pulling the lever, the cocks *b* and *d* may be opened when the cock *e* must be shut; and the cock *e* be opened when *b* and *d* must be shut.

The boiler *E* should be inclosed in a brick-wall, at a little distance from it, all around; to give liberty for the flames of the fire under the boiler to ascend round about it. By which means, (the wall not covering the funnel *G*) the force of the steam will be prodigiously increased by the heat round the boiler; and the funnel and water in it will be heated from the boiler; so that, the boiler will not be chilled by letting cold water into it; and the rising of the steam will be so much the quicker.

Mr. *Blakey* is the only person who ever thought of making use of air as an intermediate body between steam and water: by which means, the steam is always kept from touching the water, and consequently from being condensed by it. And, on this new principle, he has obtained a patent: so that no one (vary the engine how he will) can make use of air between steam and water, without infringing on the patent, and being subject to the penalties of the law.

This engine may be built for a trifling expence, in comparison of the common fire engine now in use: it will seldom need repairs, and will not consume half so much fuel. And as it has no pumps with pistons, it is clear of all their friction: and the effect is equal to the whole strength or compressive force of the steam; which the effect of the common fire engine never is, on account of the great friction of the pistons in their pumps.

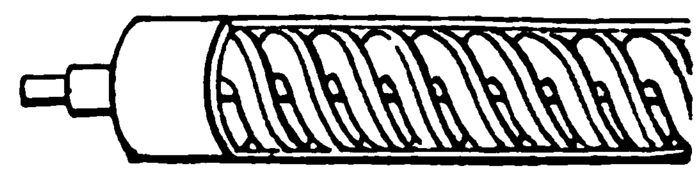
ARCHIMEDES'S *Screw-engine for raising Water.*



A B C D is a wheel, which is turned round, accord-

ing to the order of the letters, by the fall of water *E F*, which need not be more than three feet. The axle *G* of the wheel is elevated so, as to make an angle of about 44 degrees with the horizon; and on the top of that axle is a wheel *H*, which turns such another wheel *I* of the same number of teeth: the axle *K* of this last wheel being parallel to the axle *G* of the two former wheels.

The axle *G* is cut into a double-threaded screw exactly resembling the screw on the axis of the fly of a common jack, which must be (what is called) a right-handed screw, like the wood-screws, if the first wheel turns in the direction *A B C D*; but must be a left-handed screw, if the steam turns the wheel the contrary way. And, which ever way the screw on the axle *G* be cut, the screw on the axle *K* must be cut the contrary way; because these axles turn in contrary directions.



The screws being thus cut, they must be covered close over with boards like those of a cylindrical cask; and then they will be spiral tubes. Or, they may be made of tubes of stiff leather, and wrapt round the axles in shallow grooves cut therein.

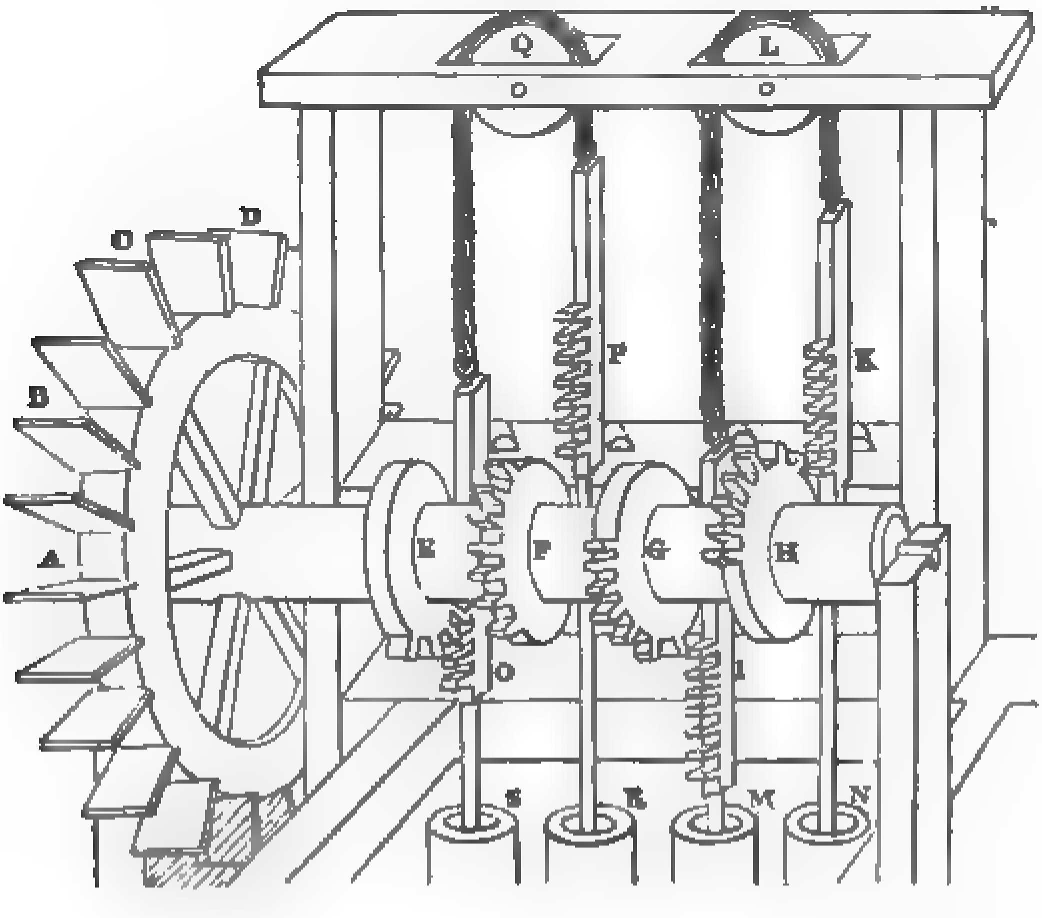
The lower end of the axle *G* turns constantly in the stream that turns the wheel, and the lower ends of the spiral tubes are open into the water. So that, as the wheel and axle are turned round, the water rises in the spiral tubes, and runs out at *L*, through the holes *M*, *N*, as they come about below the axle. These holes (of which there may be any number, as four or six) are in a broad close ring on the top of the axle, into

which ring, the water is delivered from the upper open ends of the screw-tubes, and falls into the open box *N*.

The lower end of the axle *K* turns on a gudgeon, in the water in *N*; and the spiral tubes in that axle take up the water from *N*, and deliver it into such another box under the top of *K*; on which there may be such another wheel as *I*, to turn a third axle by such a wheel upon it.——And in this manner, water may be raised to any given height, when there is a stream sufficient for that purpose to act on the broad float boards of the first wheel.

A quadruple Pump-mill for raising Water.

This engine is represented thus: In which *A B C D* is a wheel, turned by water according to the order of



the letters. On the horizontal axis are four small wheels, toothed almost half round: and the parts of their edges

on which there are no teeth are cut down so, as to be even with the bottoms of the teeth where they stand.

The teeth of these four wheels take alternately into the teeth of four racks, which hang by two chains over the pullies *Q* and *L*; and to the lower ends of these racks there are four iron rods fixed, which go down into the four forcing pumps, *S*, *R*, *M* and *N*. And, as the wheels turn, the racks and pump-rods are alternately moved up and down.

Thus, suppose the wheel *G* has pulled down the rack *I*, and drawn up the rack *K* by the chain: as the last tooth of *G* just leaves the uppermost tooth of *I*, the first tooth of *H* is ready to take into the lowermost tooth of the rack *K*, and pull it down as far as the teeth go; and then the rack *I* is pulled upward through the whole space of its teeth, and the wheel *G* is ready to take hold of it, and pull it down again, and so draw up the other.——In the same manner, the wheels *E* and *F* work the racks *O* and *P*.

These four wheels are fixed on the axle of the great wheel in such a manner, with respect to the positions of their teeth, that, whilst they continue turning round, there is never one instant of time in which one or other of the pump-rods is not going down, and forcing the water. So that, in this engine, there is no occasion for having a general air-vessel to all the pumps, to procure a constant stream of water flowing from the upper end of the main pipe.

There is an engine of this sort, described in *Ramelli's* work, but I can truly say, that I never saw it till some time after I had made this model.

The said model is not above twice as big as the figure of it, here described. I turn it by a winch fixed on the gudgeon of the axle behind the water wheel; and, when it was newly made, and the pistons and valves in good order, I put tin pipes 15 feet high upon

Fig 2.

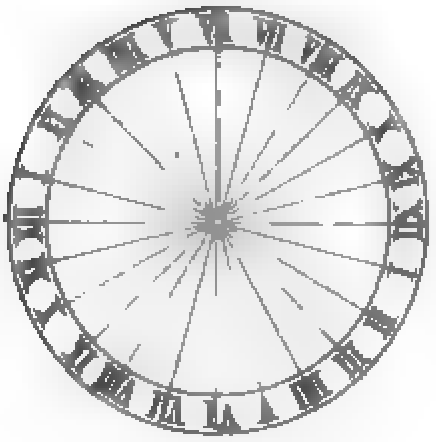


Fig 3.

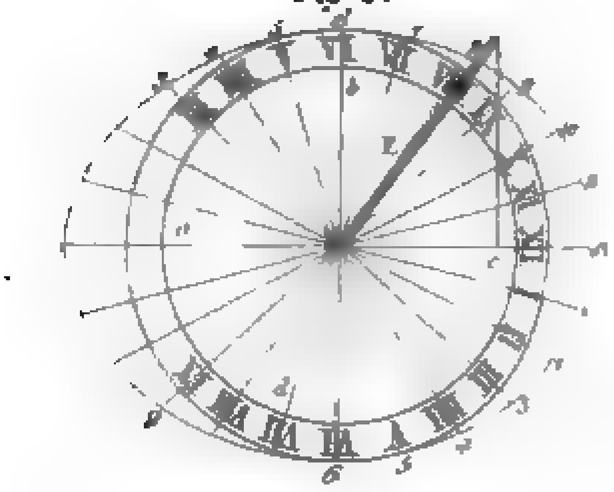


Fig. 4

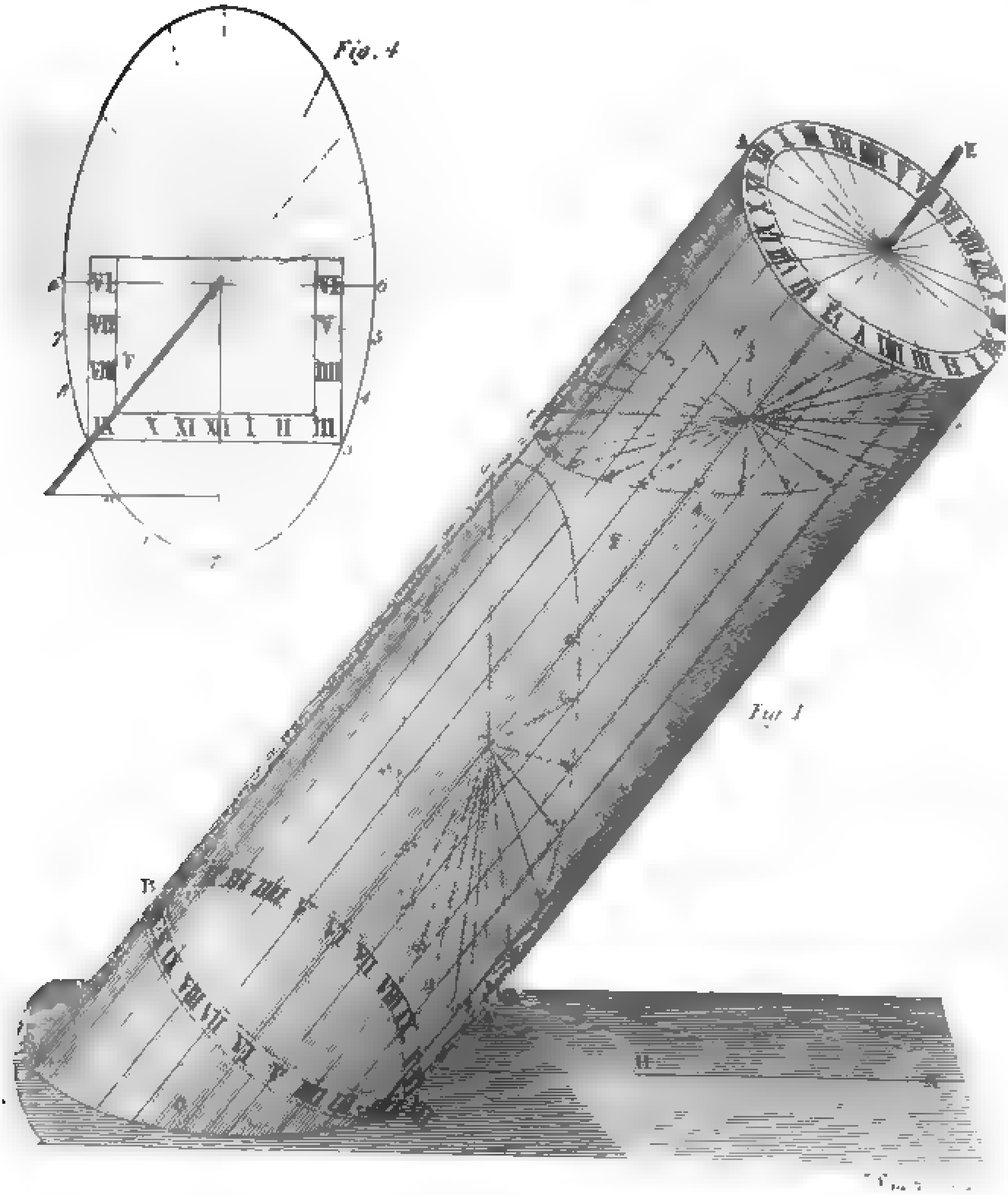


Fig 1

it, when they were joined together, to see what it could do. And I found, that in turning it moderately by the winch, it would raise a hogshead of water in an hour to the height of 15 feet.

The universal Dialing Cylinder.

In Fig. 1. of Plate VII. *A B C D* represent a cylindrical glass tube, closed at both ends with brass plates, and having a wire or axis *E F G* fixed in the centers of the brass plates at top and bottom. This tube is fixed to a horizontal board *H*, and its axis makes an angle with the board equal to the angle of the earth's axis with the horizon of any given place, for which the cylinder is to serve as a dial. And it must be set with its axis parallel to the axis of the world in that place; the end *E* pointing to the elevated pole. Or, it may be made to move upon a joint; and then it may be elevated for any particular latitude.

There are 24 straight lines, drawn with a diamond, on the outside of the glass, equidistant from each other, and all of them parallel to the axis. These are the hour-lines; and the hours are set to them as in the figure: the XII. next *B* stands for midnight, and the opposite XII, next the board *H*, stands for mid-day or noon.

The axis being elevated to the latitude of the place, and the foot-board set truly level, with the black line along its middle in the plane of the meridian, and the end *N* toward the north; the axis *E F G* will serve as a stile or gnomon, and cast a shadow on the hour of the day, among the parallel hour-lines when the sun shines on the machine. For, as the sun's apparent diurnal motion is equable in the heavens, the shadow of the axis will move equably in the tube; and will always fall upon *that* hour-line which is opposite to the sun, at any given time.[133]

Note 133. It is evident, that if the cylinder were placed within a

The brass plate $A\ D$, at the top, is parallel to the equator, and the axis $E\,F\,G$ is perpendicular to it. If right lines be drawn from the center of this plate, to the upper ends of the equidistant parallel lines on the outside of the tube; these right lines will be the hour-lines on the equinoctial dial $A\ D$, at 15 degrees distance from each other, and the hour-letters may be set to them as in the figure. Then, as the shadow of the axis within the tube comes on the hour-lines of the tube, it will cover the like hour-lines on the equinoctial plate $A\ D$.

If a thin horizontal plate $e\,f$ be put within the tube, so as its edge may touch the tube all around; and right lines be drawn from the center of that plate to those points of its edge which are cut by the parallel hour-lines on the tube; these right lines will be the hour-lines of a horizontal dial, for the latitude to which the tube is elevated. For, as the shadow of the axis comes successively to the hour-lines of the tube, and covers them, it will then cover the like hour-lines on the horizontal plate $e\,f$, to which the hours may be set, as in the figure.[134]

If a thin vertical plate $g\ C$, be put within the tube, so as to front the meridian or 12 o'clock line thereof, and the edge of this plate touch the tube all around; and then, if right lines be drawn from the center of the plate to those points of its edge which are cut by the parallel hour-lines on the tube; these right-lines will be hour-lines of a vertical south-dial: and the shadow of the axis will cover them at the same times when it covers those of the tube.

sphere, so that the axis of both solids should coincide, the projections of the hour-lines of the sphere, upon the surface of the cylinder, would be at equal distances from each other. In other words, the hour-lines of the cylinder would be equidistant.

Note 134. The dialing cylinder, like the globe, must be considered as useful rather as an illustration than as a method of describing dials.

If a thin plate be put within the tube so as to decline, or incline, or recline, by any given number of degrees; and right lines be drawn from its center to the hour-lines of the tube; these right lines will be the hour-lines of a declining, inclining, or reclining dial, answering to the like number of degrees, for the latitude to which the tube is elevated.

And thus, by this simple machine, all the principles of dialing are made very plain and evident to the sight. And the axis of the tube (which is parallel to the axis of the world in every latitude to which it is elevated) is the stile or gnomon for all the different kinds of sun-dials.

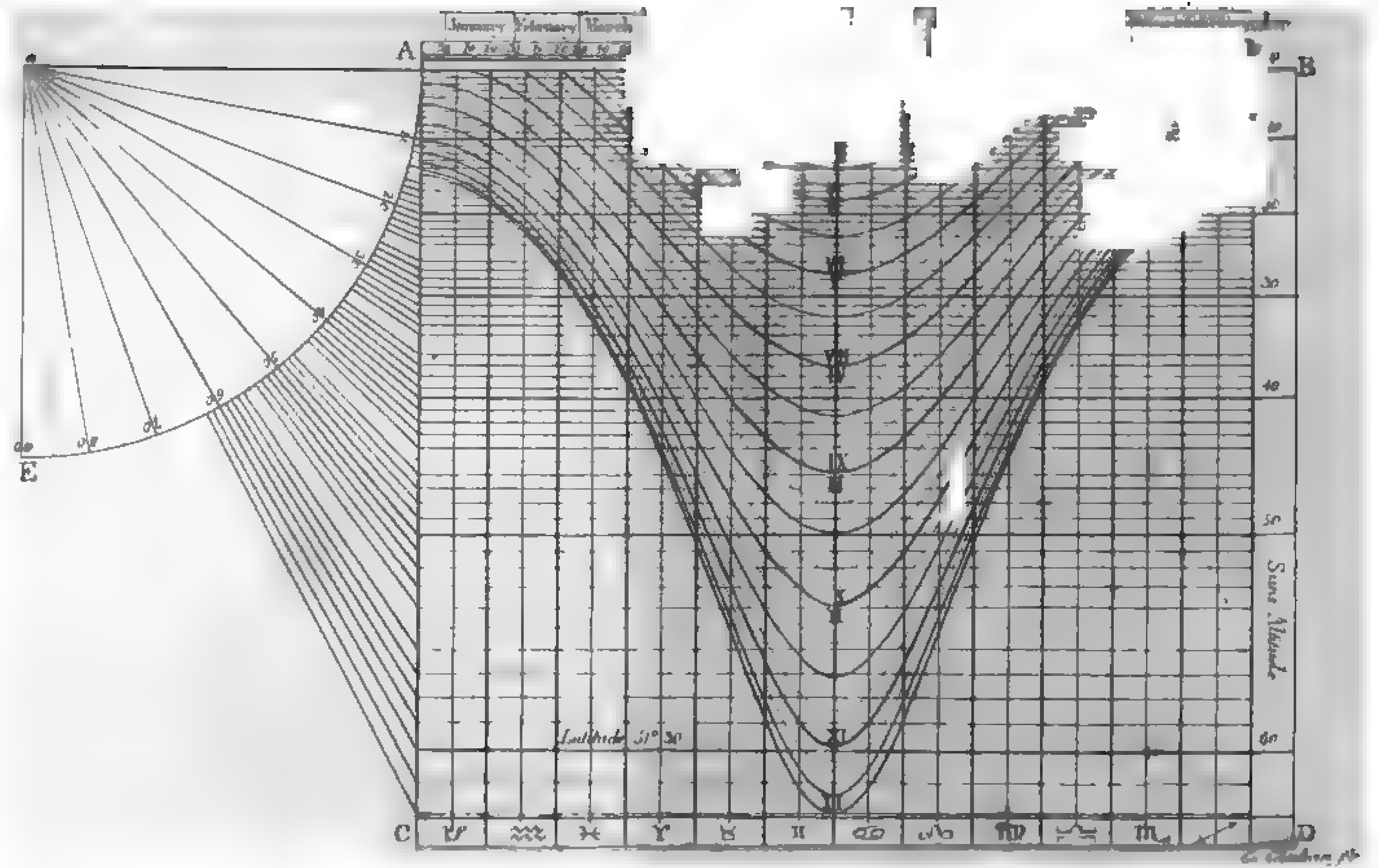
And lastly, if the axis of the tube be drawn out, with the plates *A D*, *e f*, and *g C* upon it; and set it up in sun-shine, in the same position as they were in the tube; you will have an equinoctial dial *A D*, a horizontal dial *e f*, and a vertical south dial *g C*; on all which, the time of the day will be shown by the shadow of the axis or gnomon *E F G*.

Let us now suppose that, instead of a glass tube, *A B C D* is a cylinder of wood; on which the 24 parallel hour lines are drawn all around, at equal distances from each other; and that, from the points at top, where these lines end, right lines are drawn toward the center, on the flat surface *A D*: these right lines will be the hour-lines on an equinoctial dial, for the latitude of the place to which the cylinder is elevated above the horizontal foot or pedestal *H*; and they are equidistant from each other, as in Fig. 2. which is a full view of the flat surface or top *A D* of the cylinder, seen obliquely in Fig. 1. And the axis of the cylinder (which is a straight wire *E F G* all down its middle) is the stile or gnomon; which is perpendicular to the plane of the equinoctial dial, as the earth's axis is perpendicular to the plane of the equator

To make a horizontal dial, by the cylinder, for any latitude to which its axis is elevated; draw out the axis and cut the cylinder quite through, as at *e h f g*, parallel to the horizontal board *H*, and take off the top part *e A D f e;* and the section *e h f g e* will be of an elliptical form, as in *Fig.* 3. Then, from the points of this section (on the remaining part *e B C f*) where the parallel lines on the outside of the cylinder meet it, draw right-lines to the center of the section; and they will be the true hour-lines for a horizontal dial, as *a b c d e* in *Fig.* 3. which may be included in a circle drawn on that section. Then, put the wire into its place again, and it will be a stile for casting a shadow on the time of the day, on that dial. So, *E* (Fig. 3.) is the stile of the horizontal dial, parallel to the axis of the cylinder.

To make a vertical south dial by the cylinder, draw out the axis, and cut the cylinder perpendicularly to the horizontal board *H*, as at *g i C k g*, beginning at the hour line (*B g e A*) of XII. and making the section at right angles to the line *S H N* on the horizontal board. Then, take off the upper part *g A D C*, and the face of the section thereon will be elliptical, as shewn in Fig. 4. From the points in the edge of this section, where the parallel hour-lines on the round surface of the cylinder meet it, draw right-lines to the center of the section; and they will be the true hour-lines on a vertical direct south dial, for the latitude to which the cylinder was elevated: and will appear as in Fig. 4. on which the vertical dial may be made of a circular shape, or of a square shape as represented in the figure. And *F* will be its stile parallel to the axis of the cylinder.

And thus, by cutting the cylinder any way, so that its section may either incline, or decline, or recline, by any given number of degrees; and from those points in the edge of the section where the outside parallel hour-lines meet it, draw right lines to the center of the section ·



January
February
March
A
B
C
D
E
Suns Altitude
Latitude 51° 30

and they will be the true hour-lines, for the like declining, reclining, or inclining dial. And the axis of the cylinder will always be the gnomon or stile of the dial. For, whichever way the plane of the dial lies, its stile (or the edge thereof that casts the shadow on the hours of the day) must be parallel to the earth's axis, and point toward the elevated pole of the heavens.

To delineate a Sun-dial on Paper; which, when pasted round a Cylinder of Wood, shall shew the Time of the Day, the Sun's Place in the Ecliptic, and his Altitude, at any Time of Observation. See Plate VIII.

Draw the right line *a A B*, parallel to the top of the paper; and, with any convenient opening of the compasses, set one foot in the end of the line at *a*, as a center, and with the other foot describe the quadrantal arc *A E*, and divide it into 90 equal parts or degrees. Draw the right line *A C*, at right angles to *a A B*, and touching the quadrant *A E* at the point *A*. Then, from the center *a*, draw right lines through as many degrees of the quadrant, as are equal to the sun's altitude at noon, on the longest day of the year, at the place for which the dial is to serve; which altitude, at London, is 62 degrees: and continue these right lines till they meet the tangent line *A C*; and, from these points of meeting, draw straight lines across the paper, parallel to the first right line *A B*, and they will be the parallels of the sun's altitude, in whole degrees, from sun-rise till sunset, on all the days of the year.—These parallels of altitude must be drawn out to the right line *B D*, which must be parallel to *A C*, and as far as is equal to the intended circumference of the cylinder on which the paper is to be pasted, when the dial is drawn upon it.

Divide the space between the right lines *A C* and *B D* (at top and bottom) into twelve equal parts, for

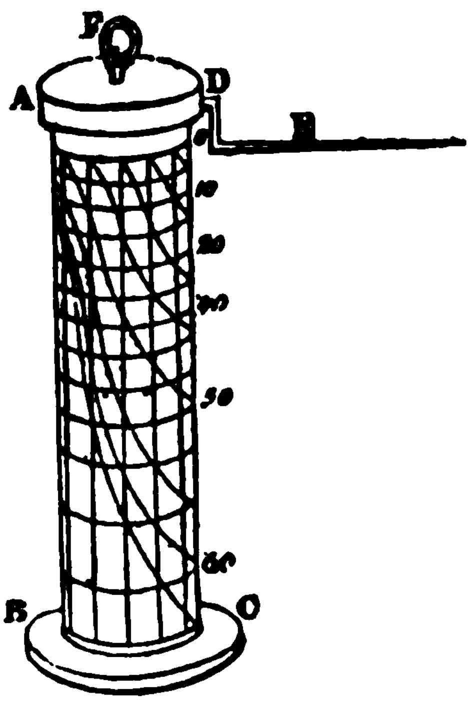
the twelve signs of the ecliptic; and, from mark to mark, of these divisions at top and bottom, draw right lines parallel to $A\ C$ and $B\ D$; and place the characters of the 12 signs in these twelve spaces, at the bottom, as in the figure: beginning with ♑ or Capricorn, and ending with ♓ or Pisces. The spaces including the signs should be divided by parallel lines into halves; and, if the breadth will admit of it without confusion, into quarters also.

At the top of the dial, make a scale of the months and days of the year, so that the days may stand over the sun's place for each of them in the signs of the ecliptic. The sun's place, for every day of the year, may be found by any common ephemeris: and here it will be best to make use of an ephemeris for the second year after leap-year; as the nearest mean for the sun's place on the days of the leap-year, and on those of the first, second, and third years after.

Compute the sun's altitude for every hour (in the latitude of your place) when he is in the beginning, middle, and end of each sign of the ecliptic; his altitnde at the end of each sign being the same as at the beginning of the next. And, in the upright parallel lines, at the beginning and middle of each sign, make marks for these computed altitudes among the horizontal parallels of altitude, reckoning them downward, according to the order of the numeral figures set to them at the right hand, answering to the like divisions of the quadrant at the left. And, through these marks, draw the curve hour-lines, and set the hours to them, as in the figure, reckoning the forenoon hours downward, and the afternoon hours upward.——The sun's altitude should also be computed for the half hours; and the quarter lines may be drawn, very nearly in their proper places, by estimation and accuracy of the eye. Then, cut off the paper at the left hand, on which the quadrant

was drawn, close by the right line *A C*, and all the paper at the right hand close by the right line *B D;* and cut it also close by the top and bottom horizontal lines; and it will be fit for pasting round the cylinder.

This cylinder is represented in miniature thus: It should be hollow, to hold the stile *D E* when it is not used. The crooked end of the stile is put into a hole in the top *A D* of the cylinder; and the top goes on tightish, but must be made to turn round on the cylinder, like the lid of a paper snuff-box. The stile must stand straight out, perpendicular to the side of the cylinder, just over the right line *A B* in Plate VIII. where the parallels of the sun's altitude begin :and the length of the stile, or distance of its point *e* from the cylinder, must be equal to the radius *a A* of the quadrant *A E* in Plate VIII.



The Method of using this Dial is as follows

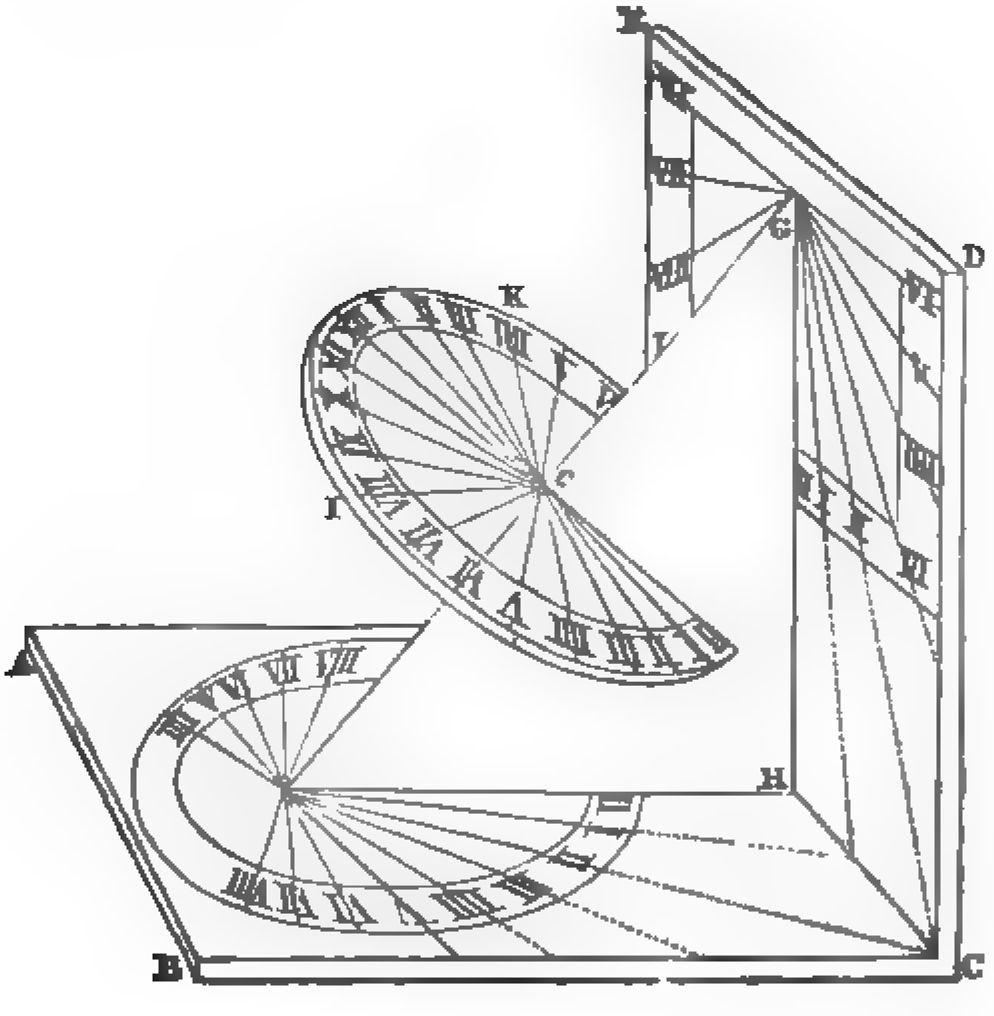
Place the horizontal foot *B C* of the cylinder on a level table where the sun shines, and turn the top *A D* till the stile stands just over the day of the then present month. Then turn the cylinder about on the table, till the shadow of the stile falls upon it, parallel to these upright lines which divide the signs; that is, till the shadow be parallel to a supposed axis in the middle of the cylinder: and then, the point, or lowest end of the shadow, will fall upon the time of the day, as it is before or after noon, among the curve hour-lines; and it will shew the sun's altitude at that time, among the cross parallels of his altitude, which go round the cy-

linder: and, at the same time, it will shew in what sign of the ecliptic the sun then is, and you may very nearly guess at the degree of the sign, by estimation of the eye.

When a level table cannot be had, the dial may be hung by the ring *F* at the top. And when it is not used, the wire that serves for a stile may be drawn out and put up within the cylinder; and the machine carried in the pocket.

To make three Sun-dials upon three different Planes, so that they may all shew the Time of the Day by one Gnomon.

On the flat board *A B C*, describe a horizontal dial,



according to any of the rules laid down in the Lecture

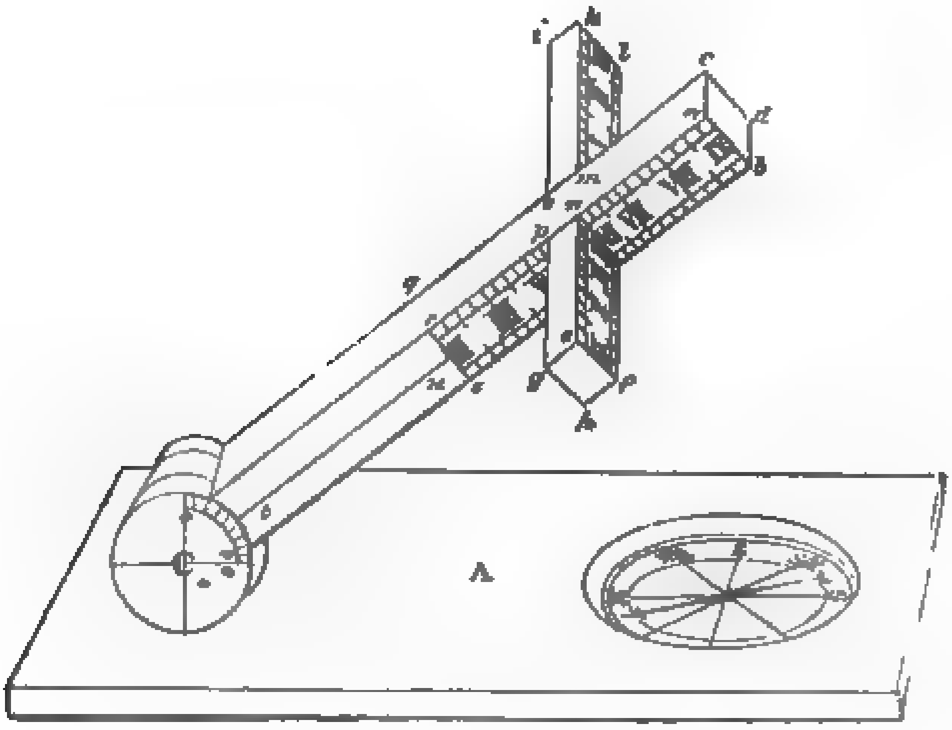
on dialing; and to it fix its gnomon *F G H*, the edge of the shadow from the side *F G* being that which shews the time of the day.

To this horizontal or flat board, join the upright board *E D C*, touching the edge *G H* of the gnomon. Then, making the top of the gnomon at *H* the center of the vertical south dial, describe a south dial on the board *E D C*.

Lastly, on a circular plate *I K* describe an equinoctial dial, all the hours of which dial are equidistant from each other; and making a slit *c d* in that dial, from its edge to its center, in the XII o'clock line; put the said dial perpendicularly on the gnomon *F G*, as far as the slit will admit of; and the triple dial will be finished; the same gnomon serving all the three, and shewing the same time of the day on each of them.

A universal Dial on a plain Cross.

This dial is thus represented: and is moveable on a



joint *C*, for elevating it to any given latitude, on the quadrant *C* 090, as it stands upon the horizontal board

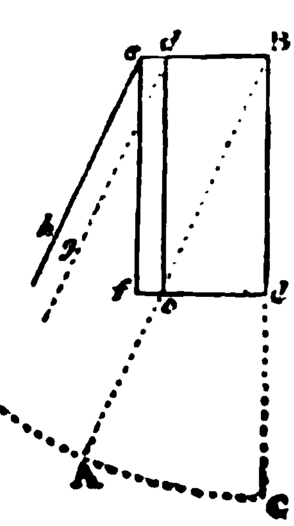
A. The arms of the cross stand at right angles to the middle part; and the top of it, from *a* to *n* is of equal length with either of the arms *n e* or *m k*.

Having set the middle line *t u* to the latitude of your place, on the quadrant, the board *A* level, and the point *N* northward by the needle; the plane of the cross will be parallel to the plane of the equator; and the machine will be rectified.

Then, from III o'clock in the morning, till VI, the upper edge *k l* of the arm *i o* will cast a shadow on the time of the day on the side of the arm *c m:* from VI till IX, the lower edge *i* of the arm *i o* will cast a shadow on the hours on the side *o q*. From IX in the morning to XII at noon, the edge *a b* of the top part *a n* will cast a shadow on the hours on the arm *n e f*: from XII to III in the afternoon, the edge *c d* of the top part will cast a shadow on the hours on the arm *k l m:* from III to VI in the evening, the edge *g h* will cast a shadow on the hours of the part *p q;* and from VI till IX, the shadow of the edge *e f* will shew the time on the top part *a n*.

The breadth of each part, *a b*, *e f*, &c. must be so great as never to let the shadow fall quite without the part or arm on which the hours are marked, when the sun is at his greatest declination from the equator.

To determine the breadth of the sides of the arms which contain the hours, so as to be in just proportion to their length; make an angle *A B C* of 23½ degrees, which is equal to the sun's greatest declination: and suppose the length of each arm, from the side of the long middle part, and also the length of the top part above the arms, to be equal to *B d*.

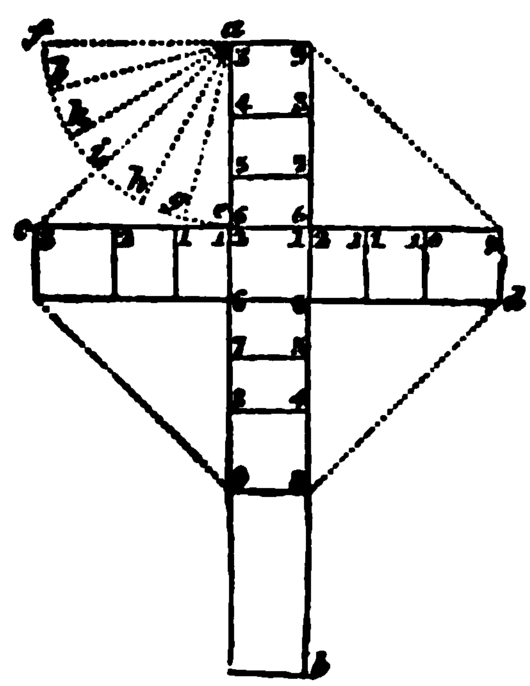


Then, as the edges of the shadow, from each of the arms, will be parallel

to *B e*, making an angle of 23½ degrees with the side *B d* of the arm when the sun's declination is 23½ degrees; it is plain, that if the length of the arm be *B d*, the least breadth that it can have, to keep the edge *B e* of the shadow *B e g d* from going off the side of the arm *d e* before it comes to the end *e d* thereof, must be equal to *e d* or *d B*. But, in order to keep the shadow within the quarter divisions of the hours, when it comes near the end of the arm, the breadth thereof should be still greater, so as to be almost doubled, on account of the distance between the tips of the arms.

To place the hours right on the arms, take the following method:

Lay down the cross *a c b d* on a sheet of paper; and with a black-lead pencil, held close to it, draw its shape and size on the paper. Then taking the length *a e* in your compasses, and setting one foot in the corner *A*, with the other foot describe the quadrantal arc *e f*.—Divide this arc into six equal parts, and through the division marks draw right lines *a g*, *a h*, &c. continuing



three of them to the arm *c e*, which are all that can fall upon it; and they will meet the arm in these points through which the lines that divide the hours from each other (as in former figure) are to be drawn right across it.

Divide each arm, for the three hours it contains, in the same manner; and set the hours to their proper places (on the sides of the arms,) as they are marked in the previous figure. Each of the hour spaces should be divided into four equal parts, for the half hours and

quarters, in the quadrant *e f*; and right lines should be drawn through these division-marks in the quadrant, to the arms of the cross; in order to determine the places thereon where the sub-divisions of the hours must be marked.

This is a very simple kind of universal dial; it is very easily made, and will have a pretty and uncommon appearance in a garden.—I have seen a dial of this sort, but never saw one of the kind that follows.

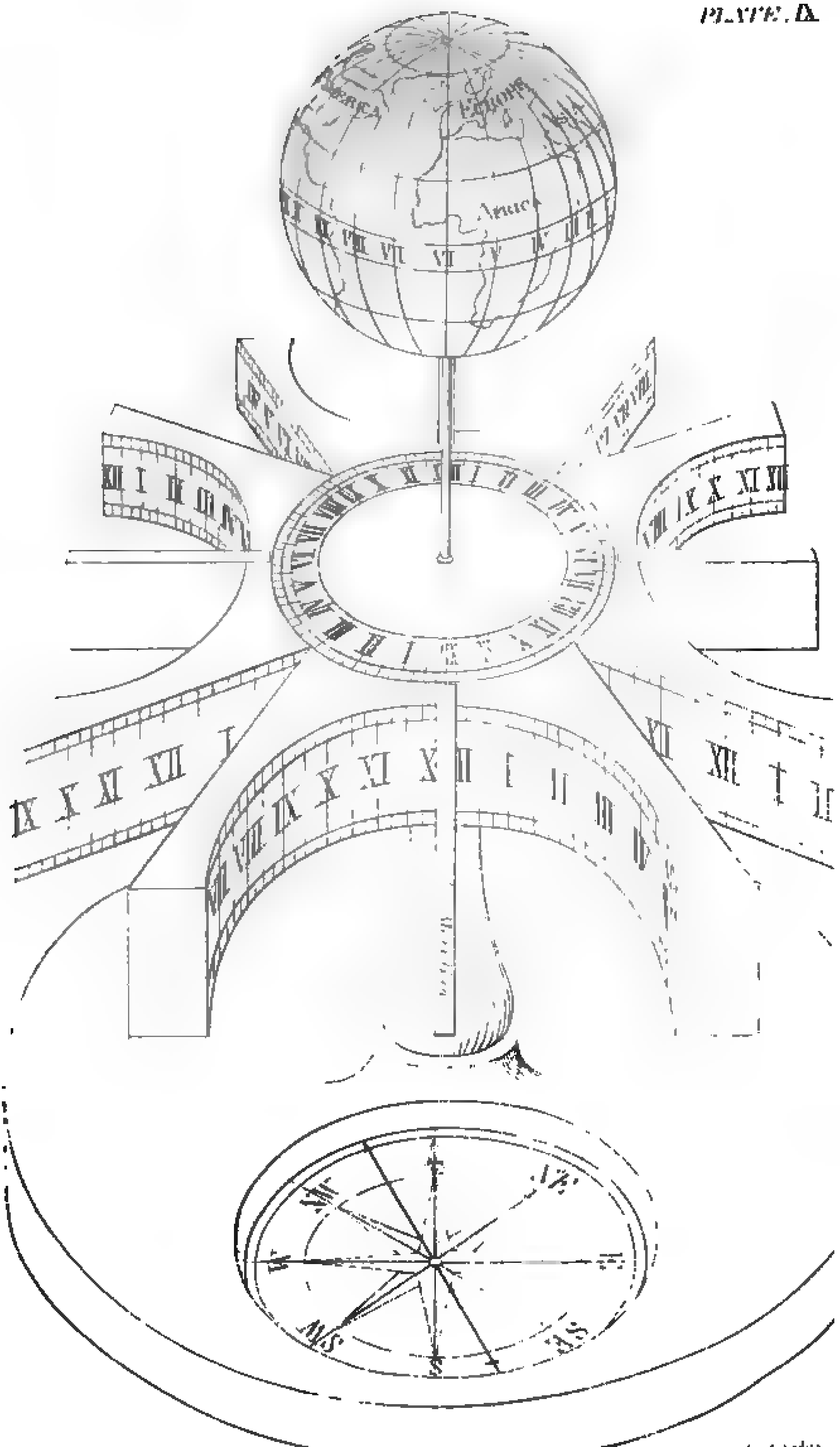
A universal Dial, shewing the Hours of the Day by a terrestrial Globe, and by the Shadows of several Gnomons, at the same time: together with all the Places of the Earth which are then enlightened by the Sun; and those to which the Sun is then rising, or on the Meridian, or Setting.

This dial (see Plate IX.) is made of a thick square piece of wood, or hollow metal. The sides are cut into semi-circular hollows, in which the hours are placed; the stile of each hollow coming out from the bottom thereof, as far as the ends of the hollows project. The corners are cut out into angles, in the insides of which, the hours are also marked; and the edge of the end of each side of the angle serves as a stile for casting a shadow on the hours marked on the other side.

In the middle of the uppermost side or plane, there is an equinoctial dial; in the center whereof, an upright wire is fixed, for casting a shadow on the hours of that dial, and supporting a small terrestrial globe on its top.

The whole dial stands on a pillar, in the middle of a round horizontal board, in which there is a compass and magnetic needle, for placing the *meridian* stile towards the south. The pillar has a joint with a quadrant upon it, divided into 90 degrees (supposed to be hid from sight under the dial in the figure,) for setting it to the latitude of any given place; the same way as already described in the dial on the cross.

PLATE. IX.



The equator of the globe is divided into twenty-four equal parts, and the hours are laid down upon it at these parts. The time of the day may be known by these hours, when the sun shines upon the globe

To rectify and use this dial, set it on a level table, or sole of a window, where the sun shines, placing the meridian stile due south, by means of the needle; which will be, when the needle points as far from the north fleur-de-lis toward the west, as it declines westward at your place. Then bend the pillar in the joint, till the black line on the pillar comes to the latitude of your place in the quadrant.

The machine being thus rectified, the plane of its dial part will be parallel to the equator, the wire or axis that supports the globe will be parallel to the earth's axis, and the north pole of the globe will point toward the north pole of the heavens.

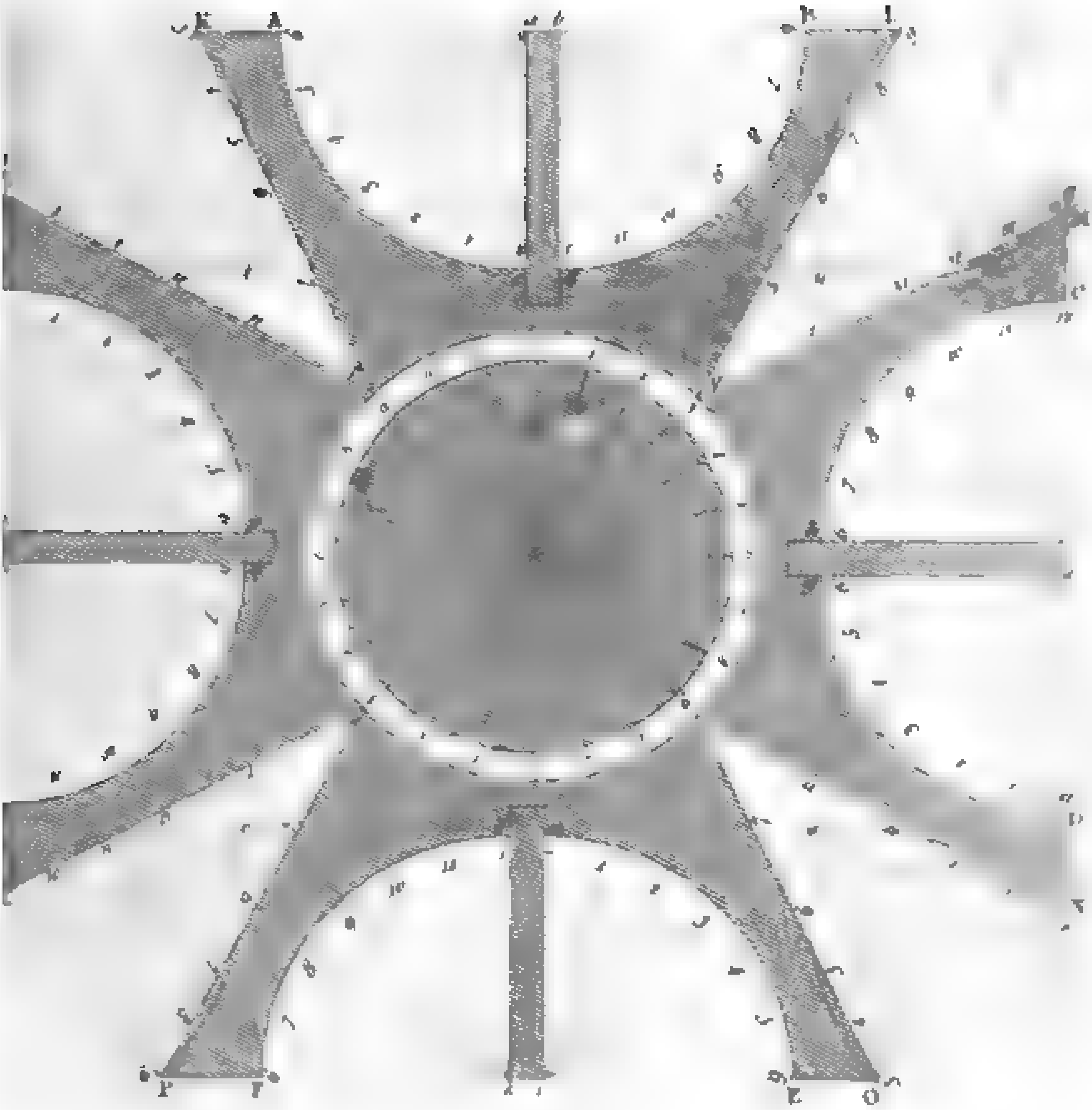
The same hour will then be shewn in several of the hollows, by the ends of the shadows of their respective stiles: The axis of the globe will cast a shadow on the same hour of the day, in the equinoctial dial, in the center of which it is placed, from the 20th of March to the 23rd of September; and, if the meridian of your place on the globe be set even with the meridian stile, all the parts of the globe that the sun shines upon, will answer to those places of the real earth which are then enlightened by the sun. The places where the shade is just coming upon the globe, answer to all those places of the earth to which the sun is then setting; as the places where it is going off, and the light coming on, answer to all the places of the earth where the sun is then rising. And lastly, if the hour of VI be marked on the equator in the meridian of your place (as it is marked on the meridian of London in the figure) the division of the light and shade on the globe will shew the time of the day.

The northern stile of the dial (opposite to the southern or meridian one) is hid from sight in the figure, by the axis of the globe. The hours in the hollow to which that stile belongs, are also supposed to be hid by the oblique view of the figure: but they are the same as the hours in the front hollow. Those also in the right and left hand semicircular hollows are mostly hid from sight; and so also are all those on the sides next the eye of the four acute angles.

The construction of this dial is as follows, (See Plate X. On a thick square piece of wood, or metal, draw the lines *a c* and *b d*, as far from each other as you intend for the thickness of the stile *a b c d;* and in the same manner, draw the like thickness of the other three stiles, *e f g h*, *i k l m*, and *n o p q*, all standing outright as from the center.

With any convenient opening of the compasses, as *a A* (so as to leave proper strength of stuff when *K I* is equal to *a A*) set one foot in *a*, as a center, and with the other foot describe the quadrantal arc *A c*. Then without altering the compasses, set one foot in *b* as a center, and with the other foot describe the quadrant *d B*. All the other quadrants in the figure must be described in the same manner, and with the same opening of the compasses, on their centers *e f; i k;* and *n o:* and each quadrant divided into 6 equal parts, for so many hours, as in the figure; each of which parts must be subdivided into 4, for the half hours and quarters.

At equal distances from each corner, draw the right lines *i p* and *K p*, *L q* and *M q*, *N r* and *O r*, *P s* and *Q s;* to form the four angular hollows *I p K*, *L q M*, *N r O*, and *P s Q;* making the distances between the tips of these hollows, as *I K*, *L M*, *N O*, and *P Q*, each equal to the radius of the quadrants; and leaving sufficient room within the angular points, *p*, *q*, *r*, and *s*, for the equinoctial in the middle.



To divide the insides of these angles properly, for the hour-spaces thereon, take the following method:

Set one foot of the compasses in the point *I*, as a center: and open the other to *K*, and with that opening, describe the arc *Kt*: then, without altering the compasses, set one foot in *K*, and with the other foot describe the arc *It*. Divide each of these arcs, from *I* and *K* to their intersection at *t*, into four equal parts; and from their centers *I* and *K*, through the points of division, draw the right lines *I* 3, *I* 4, *I* 5, *I* 6, *I* 7; and *K* 2, *K* 1, *K* 12, *K* 11; and they will meet the sides *Kp* and *Ip* of the angle *IpK* where the hours thereon must be placed. And these hour-spaces in the arcs must be subdivided into four equal parts, for the half hours and quarters;—Do the like for the other three angles, and draw the dotted lines, and set the hours in the insides where those lines meet them as in the figure: and the like hour-lines will be parallel to each other in all the quadrants and in all the angles.

Mark points for all these hours, on the upper side; and cut out all the angular hollows, and the quadrantal ones quite through the places where their four gnomons must stand; and lay down the hours on their insides, as in Plate IX, and then set in their four gnomons, which must be as broad as the dial is thick; and this breadth and thickness must be large enough to keep the shadows of the gnomons from ever falling quite out at the sides of the hollows, even when the sun's declination is at the greatest.

Lastly, draw the equinoctial dial in the middle, all the hours of which are equidistant from each other; and the dial will be finished.

As the sun goes round, the broad end of the shadow of the stile *abcd* will shew the hours in the quadrant *Ac*, from sun rise till VI in the morning; the shadow

from the end *M* will shew the hours on the side *Lq* from V to IX in the morning; the shadow of the stile *efgh* in the quadrant *Dg* (in the long days) will shew the hours from sun-rise till VI in the morning; and the shadow of the end *N* will shew the morning hours, on the side *Or*, from III to VII.

Just as the shadow of the northern stile *abcd* goes off the quadrant *Ac*, the shadow of the southern stile *iklm* begins to fall within the quadrant *Fl*, at VI in the morning; and shews the time, in that quadrant, from VI till XII at noon; and from noon till VI in the evening in the quadrant *mE*. And the shadow of the end *O*, shews the time from XI in the forenoon till III in the afternoon, on the side *rN*; as the shadow of the end *P* shews the time from IX in the morning till I o'clock in the afternoon, on the side *Qs*.

At noon, when the shadow of the eastern stile *efgh* goes off the quadrant *hC* (in which it shewed the time from VI in the morning till noon, as it did in the quadrant *gD* from sun-rise till VI in the morning) the shadow of the western stile *nopq* begins to enter the quadrant *Hp*; and shews the hours thereon from XII at noon till six in the evening; and after *that* till sun-set, in the quadrant *qG*: and the end *Q* casts a shadow on the side *Ps* from V in the evening till IX at night, if the sun be not set before that time.

The shadow of the end *I* shews the time on the side *Kp* from III till VII in the afternoon; and the shadow of the stile *abcd* shews the time from VI in the evening till the sun sets.

The shadow of the upright central wire, that supports the globe at top, shews the time of the day, in the middle or equinoctial dial, all the summer half year, when the sun is on the north side of the equator.

In this supplement to my book of Lectures, all the machines that I have added to my apparatus, since that

book was printed, are described, excepting two; one of which is a model of a mill for sawing timber, and the other is a model of the great engine at London-bridge, for raising water. And my reasons for leaving them out are as follow.

First, I found it impossible to make such a drawing of the saw-mill as could be understood; because, in whatever view it be taken, a great many parts of it hide others from sight. And, in order to shew it in my Lectures, I am obliged to turn it into all manner of positions.

Secondly, Because any person who looks on that Plate of the book in which *Mr. Aldersea's* engine is described, and reads the account of it in the fifth Lecture therein, will be able to form a very good idea of the London bridge engine, which has only two wheels and two trundles more than there are in *Mr. Aldersea's* engine, from which the said figure was taken.

FINIS.

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